FLOOD PROTECTION PLANS FOR CUMBERLAND, MARYLAND & RIDGELEY WEST VIRGINIA

Hydraulic Model Investigation

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PREFACE

The model study described herein was requested by the District Engineer, Washington District, CE, in letter to the Division Engineer, Middle Atlantic Division, Baltimore, Maryland, dated 4 December 1943, and authority for the study was granted by the Chief of Engineers, in 6th indorsement thereto, dated 26 January 1944. The study was conducted intermittently by the Hydraulics Division of the Waterways Experiment Station during the period January 1944 to September 1953.

Close liaison was maintained between the Washington District and the Waterways Experiment Station, chiefly through monthly progress reports, special reports, and visits. Engineers of the Waterways Experiment Station inspected the prototype area and discussed the problems with representatives of the Washington District before the model study was undertaken. Periodic visits were made to the Experiment Station by representatives of the Office, Chief of Engineers, Middle Atlantic Division, Washington District, and the city of Cumberland to witness various tests and discuss results. Active in an advisory capacity were Messrs. A. E. Steere and H. E. Schwarz, engineers of the Washington District, who made periodic visits to the Experiment Station to assist in programming tests and developing plans and modifications. Results of model tests were submitted to the District Engineer upon completion of each test. Reports describing progress of the study were submitted monthly when the model study was active.

Personnel of the Waterways Experiment Station actively connected with the model study were Messrs. G. B. Fenwick, J. J. Franco, E. B. Lipscomb, R. G. Cox, J. F. Hand, and E. E. Moorhead.

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SUMMARY

Proposed improvement plans designed to protect the cities of Cumberland, Maryland, and Ridgeley, West Virginia, at the confluence of Wills Creek and North Branch of the Potomac River, from major floods were tested in a fixed-bed model constructed to an undistorted linear scale ratio of 1:60. The model reproduced approximately 1-3/4 miles of Wills Creek from its confluence with North Branch of the Potomac River to above the city limits of Cumberland, Maryland, and 4 miles of the North Branch of the Potomac River (approximately 1 mile above and 3 miles below its confluence with Wills Creek).

The model was adjusted hydraulically to three known floods and tests were conducted to determine the effects of the proposed plan of improvement included in the Survey Report Plan, to develop modifications of this plan, and to determine the relative effectiveness of several alternate plans proposed for improvement of flow conditions within the reach. Tests resulted in satisfactory designs of stilling basins, channel cross sections and alignments, levees and floodwalls, transitions, and modifications to bridge piers and abutments which will permit safe passage of the design flood.

FLOOD PROTECTION PLANS FOR CUMBERLAND, MARYLAND, AND RIDGELEY, WEST VIRGINIA

Hydraulic Model Investigation

PART I: INTRODUCTION

Location and Description of the Prototype

1. The city of Cumberland, Maryland, is located on the North Branch of the Potomac River and is the largest city in the North Branch Valley (see fig. 1). It is an important industrial and railroad center as well as a focal point for an important highway network. The main business district of Cumberland is located on Wills Creek, a tributary of the North Branch of the Potomac River. North Branch forms the city boundary for a distance of approximately 5 miles, and Wills Creek flows through the city for a distance of 1.2 miles. On the opposite side of North Branch is the town of Ridgeley, West Virginia, which is situated partly on the flood plain of the river and partly on the sharp backbone or slope of Knobly Mountain where this range dies out in the great bend of the river.

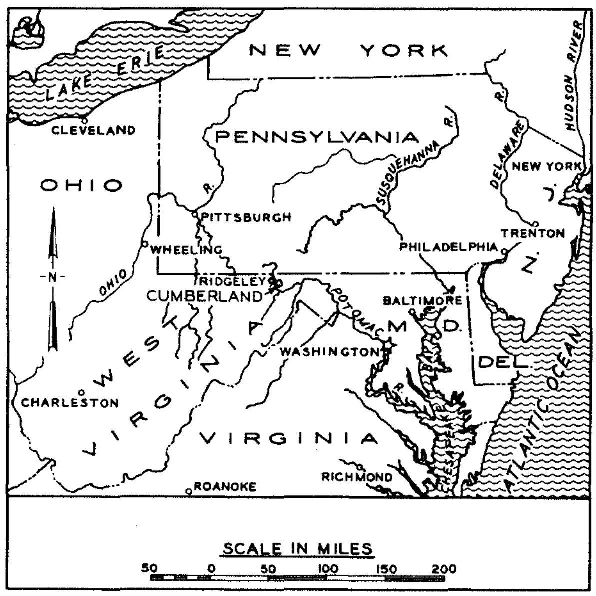


Fig. 1. Vicinity map

2. The basin of the North Branch above the confluence with Wills Creek is about 50 miles long with a maximum width of 18 miles and lies partly in the Appalachian Highlands, partly in the Appalachian Plateau, and partly in the Ridge and Valley province. The river descends from an elevation of 3200 ft msl at its source to 600 ft msl at Cumberland,

representing an average fall of about 34 ft per mile.

3. Wills Creek, one of the six principal tributaries of North Branch, drains an area of about 254 square miles, which is 35 per cent of the total drainage area of North Branch at Cumberland. The Wills Creek basin is about 35 miles long, starting in southwestern Pennsylvania and running in a southwesterly direction along the Wills Mountain range which forms its southwestern boundary. The basin descends from an elevation of 2600 ft msl at its source to 600 ft msl at Cumberland or an average fall of 57 ft per mile. The gradient of Wills Creek within the problem area is about 20 ft per mile.

4. The channels of North Branch and its tributaries are characterized as tortuous with steep slopes, high banks, and narrow flood plains. The shallow soil and steep slopes of the mountain ridges produce rapid runoff which is quickly reflected in the main streams of the basin. These factors, combined with the short time of travel to the lower reaches, result in damaging floods of relatively short duration. During the past 30 years, three disastrous floods have occurred, the greatest in March 1936. Two other floods comparable to the March 1936 flood occurred in June 1899 and March 1924, but no reliable data were obtained during either.

Recorded and Design Flood Flows

5. The storm that produced the flood of March 1936, the largest of record at Cumberland, is classed as cyclonic; it developed on the southwestern tip of the Appalachian Range and then moved north-northeastward across the basin towards Cumberland. All gages were lost during the flood, and the hydrograph was based entirely on flood marks and estimates. The peak discharge for the flood was calculated to have been 88,200 cfs. This flood is considered to have a frequency of occurrence of once in 50 years.

6. The design flows used for the reach are based upon a flood having a frequency of once in 200 years with discharges of 50,000 cfs in

Wills Creek and 63,000 cfs in North Branch, as well as other flows from these two streams producing a combined maximum discharge of 113,000 cfs at the confluence.

The Problem

7. The flood problem at Cumberland has resulted principally from the encroachment of commercial, industrial, and residential developments upon the narrow flood plains of Wills Creek and North Branch. The problem has been further complicated by a network of railroad and highway bridges having restricted channel openings which have been constructed over both streams within or adjacent to the city limits. On 22 June 1936, Congress passed the flood-control act known as "Public No. 738, 74th Congress" which authorized the construction of "Levees, retaining walls, movable dam and channel clearings to protect people and property . . ." at Cumberland, Maryland, and Ridgeley, West Virginia. As a result of this act, the District Engineer, Washington District, was directed to make a study of the flood problem at Cumberland and develop a plan of protection. All logical solutions to the problem within the fund limitations of the act seemed to dictate the construction of high floodwalls and levees through the city with traffic openings at railroad and highway bridges, and the placing of levees at considerable distance from the channels. These features were objectionable to city officials because: only partial protection was provided; the high walls proposed for Wills Creek had the effect of dividing the city into two sections; there was uncertainty as to whether quick and adequate closures of traffic openings could be made in time of flood emergency; and valuable areas of taxable property would be adversely affected. As a result of these objections, further studies were made in an effort to find a solution that would be agreeable to all concerned. These studies indicated that the complicated problem of flood control at Cumberland might best be solved, and levee and wall heights reduced, by either a low-velocity deep channel or a high-velocity channel plan for Wills Creek with dredging and other channel improvements in the North Branch downstream from Wills Creek.

Purpose of Model Study

8. Development of plans for the protection of Cumberland involved a number of unknown factors, such as the effects of changes in channel alignment and rearrangement of bridge piers and other existing structures, which could not be satisfactorily computed. In order that all phases of these problems might be studied and a basis determined for sound planning, the District Engineer requested authority to make a model study of flood conditions along Wills Creek and the North Branch at Cumberland. The general purpose of the model study was to determine the most economical method of providing protection for Cumberland and Ridgeley against floods somewhat greater than the flood of March 1936. Specifically the model was used to determine: the proper sections and grades of channels required to pass the design flood with maximum reductions in flood stages; the minimum heights of levees and walls; and the channel treatment required at bridges to insure the safe passage of floodwaters with minimum alterations to the structures.

PART II: THE MODEL

Description

9. The Cumberland flood-control model (fig. 2) was a scale reproduction of about 4 miles of the North Branch of the Potomac River (approximately 3 miles below the confluence with Wills Creek and 1 mile above) and Wills Creek from its mouth to a point approximately 1-3/4 miles upstream (see plate 1). The model was constructed of sand-cement mortar molded to templets to conform to the 1937 and 1938 prototype survey for the North Branch reach below the confluence with Wills Creek. The improved conditions based on plans prepared by the Washington District for North Branch of the Potomac above the mouth of Wills Creek and for the Wills Creek channel were installed during construction of the model. Bridges and bridge piers reproduced on the model were constructed of waterproofed wood.

Fig. 2. View of Wills Creek portion of model illustrating type of model construction used

Scale Ratios

10. The model was constructed to an undistorted linear scale ratio of 1:60, model to prototype. This scale was selected because of the necessity for accurate simulations of flows for both low- and high-velocity channels in the Wills Creek section of the model. Other scale ratios resulting from the linear scale were as follows:

Velocity	1:7.74
Discharge	1:27,900
Time	1:7.74
Roughness	1:1.98

Measurements of discharges, water-surface elevations, velocities, and current directions can be transferred quantitatively from model to prototype equivalents by means of these scale relationships.

Appurtenances

11. Model appurtenances were of the conventional type consisting of V-notched weirs for introducing flows and measuring the discharges in North Branch and Wills Creek and an adjustable tailgate for the control of tailwater. Water-surface elevations along the channel were measured by means of piezometers run to centrally located gage pits; water-surface elevations at critical points along the channel and banklines were measured by means of a portable-type point gage. Current velocities were measured with a pitot tube.

Model Adjustment

12. After construction of the model, the portion constructed to existing prototype conditions was adjusted until the model reproduced high-water elevations for the 1936, 1942, and 1937 floods. Operation of the model for this adjustment consisted of introducing inflow in Wills Creek and North Branch as estimated from flood records and maintaining the water level at gage 1 (see plate 1) corresponding to the discharge being used. The water-surface elevation in the model below

Western Maryland Railroad bridge 1657A was adjusted by the cut-and-try application of stucco for natural channel roughness, and screen wire for simulation of the roughness of underbrush and trees. Water-surface elevations at the high-water marks were measured in the model with a portable point gage, and adjustment of the model roughness was continued until the measurements in the model were reasonably close to the elevations of the high-water marks in the prototype.

13. After completion of the adjustment of that portion of the model below W.M. RR. bridge 1657A, stucco roughness of the same texture as that required for the adjustment between Smith's Island and the bridge was placed in the North Branch channel above the bridge. Stucco of the type used resulted in Manning's "n" equivalent to 0.035 to 0.040 in the prototype. Manning's "n" values (prototype) for the paved section varied from 0.015 to 0.017 and the combined "n" values of unpaved sections and paved walls averaged about 0.026. These values indicate that conditions that could be expected in the prototype were reproduced in the model with a slight tendency toward conservativeness.

PART III: TESTS OF IMPROVEMENT PLANS

Test Procedure

14. After adjustment of the model had been completed, tests were conducted with various improvement plans and modifications installed. All tests were conducted with constant flows. The desired flows for Wills Creek and North Branch of the Potomac River were introduced at the upper limits of each stream, and water-surface elevations at Wileys Ford bridge were maintained in accordance with the stage-discharge curve shown on plate 2.

15. Data obtained during the model study consisted of inflow measurements, water-surface elevations along the channel, water-surface cross sections at critical points, water-surface profiles along the banklines, velocity measurements, visual observations, and photographic records of flow conditions. More than 135 plans and modifications of plans were tested during the course of the study. Many of the plans tested were developed on the model during preliminary tests wherein changes were made as indicated by observation of flow conditions and data obtained. The principal results of the test of the final plan only are included in this report and are presented in table 1 and on plates 9 and 10.

Improvements on North Branch of Potomac

Below confluence with Wills Creek

16. Description. The design of the North Branch channel below its confluence with Wills Creek involved two considerations: the reduction of flood stages within the reach and at the mouth of Wills Creek; and the elimination or reduction of the tendency for deposition of sediment to an extent that would increase flood stages. The plan for the improvement of this reach therefore consisted of increase in channel area, channel realignment, and removal of obstructions. The features of the improvement plan as installed in the model for the final test are shown on plate 3 and included the following:

a. Dredging of channel from station 136+50 upstream through Smith's Island to station 190+00 with the existing channels around Smith's Island filled.

b. Excavating and filling channel between stations 190+00 and 220+00 so as to form a uniform slope from elevation 590.75 ft msl at station 190+00 to elevation 595.0 ft msl at station 220+00.

c. Closing the Chesapeake and Ohio Canal entrance, and raising canal towpath to confining grade from intake to a point opposite station 160+00.

d. Construction of levee on right bank between stations 178+00 and 218+00.

e. Placing blanket fill on left abutment of W.M. RR. bridge 1635.

17. Results. The results of tests of this plan are shown on plate 9 and indicate that the improvements in North Branch below its confluence with Wills Creek lowered stages for a flow comparable to the 1936 flood approximately 3 ft upstream from W.M. RR. bridge 1656, and 2 to 2.5 ft through the Smith's Island reach. The lowering of stages for the design flood (113,000 cfs) was about the same as for the 1936 flood flow above the Western Maryland Railroad bridge and slightly greater through the Smith's Island reach. The lowering of stages downstream of W.M. RR. bridge 1635 was generally less than 0.5 ft. Flood waters at design flood stage impinged against the girders of the W.M. RR. bridge 1656 (see photographs 2 and 3).

Confluence of Wills Creek and North Branch

18. Description. Several plans and modifications of plans were tested for the impingement of flow conditions at the confluence of Wills Creek and North Branch. These plans and modifications included various locations and crest lengths for the industrial dam, modifications in design of the stilling basin below the dam, dredging of the channel bed below the dam, combinations of deflection vane and splitter wall at the mouth of Wills Creek, and modifications in channel side walls. The final plan tested in the model for the confluence of the two streams is shown on plate 4 and in photograph 1 and includes the following essential features:

a. Removal of the Johnson Street bridge at station 228+50, W.M. RR. bridge 1657A, and the existing C & O Canal dam at station 221+00.

b. Construction of levees along both banks of the North Branch channel with a deflection vane at the junction of the two streams.

c. Construction at station 225+35 of an industrial dam having a 300-ft-long crest at elevation 611.5 ft msl with a bridge pier at the center and a 30-ft stilling basin.

d. Dredging of the channel bed to elevation 595.0 ft msl from station 220+00 to the end of the stilling basin below the industrial dam.

e. Paving Wills Creek channel walls, with rock bed left unpaved, from confluence with North Branch to station 9+00.

19. Results. The deflection vane at the confluence of North Branch and Wills Creek was designed to reduce the backwater effect into Wills Creek. Tests indicated that with a 100-ft splitter wall added at the end of the deflection vane, dredging below the industrial dam could be eliminated without appreciably affecting stages in Wills Creek. However, eliminating both the splitter wall and dredging below the dam would raise stages in Wills Creek as far upstream as the Baltimore Street bridge. The resulting superelevation at the left end of the industrial dam produced transverse currents along the upstream face of the dam toward the right abutment and a boil or eddy formed near that abutment, causing a deficiency of flow over the right side of the dam. This condition was improved by modification of the right bank above the dam to increase flow along the right side of the dam. With the originally proposed 10-ft-wide stilling basin, a high-velocity jet impinged on the channel bottom downstream. Tests of a section of the industrial dam were conducted on a larger scale with stilling basins 10, 20, and 30 ft wide. As a result of these tests the 30-ft-wide stilling basin was adopted for the final plan. The results of the test of the final plan for this reach are shown on plates 9 and 10 and flow conditions are shown in photographs 2 and 3.

Above confluence with Wills Creek

20. Description. Improvements in the North Branch reach above its confluence with Wills Creek consisted of the reduction of the area of the flood plain in Ridgeley, West Virginia, and in west Cumberland

by means of levees and floodwalls as shown on plate 3.

21. Results. With the final plan installed the stage just above the industrial dam was increased about 0.5 ft above that obtained with existing conditions during flows of 93,000 cfs in North Branch and 20,000 cfs in Wills Creek; stages in the reach above station 250+00 were about the same as obtained with existing conditions. (See plates 9 and 10.) For all other flow combinations tested, stages in the reach above the dam were lower than those obtained with existing conditions; this lowering amounted to about 1-1/2 ft for a flow corresponding to the March 1936 flood and extended to the upstream limits of the model.

Improvements in Wills Creek

Mouth to above Baltimore Street bridge

22. Description. A number of tests were conducted in the vicinity of the Baltimore Street bridge and W.M. RR. bridge 1659 in an effort to obtain the necessary clearance under the bridges with the least change in existing structures. The final plan tested for this reach is shown on plates 4 and 5 and in photograph 1 and included the following features:

- a. Unpaved channel bed with paved side walls from confluence with North Branch to station 9+00.
- b. Concrete channel bottom, station 9+00 to station 22+00.
- c. Construction of a high-velocity paved channel from station 12+00 to station 17+00.
- d. Replacement of the existing Baltimore Street bridge with a single-span structure.
- e. Conversion of W.M. RR. bridge 1659 to a two-span structure with a 9-ft-wide center pier having upstream and downstream transitions as shown on plate 5.

23. Results. Flood stages in the reach from the mouth of Wills Creek to about station 9+00 are controlled largely by backwater from North Branch. Water-surface slopes and velocities through this reach are relatively low and the design of the channel was determined to a large extent by the requirements at W.M. RR. bridge 1659 and the Baltimore Street bridge upstream. The final plan for the reach in the vicinity of the

Baltimore Street bridge increased velocities to supercritical for a flow of 50,000 cfs in Wills Creek and 63,000 cfs in North Branch; water-surface elevations dropped from 627.0 ft msl at station 20+00 to about 618.0 ft msl at station 13+50, downstream from which an undulating hydraulic jump occurred. The highest stage underneath the Western Maryland Railroad bridge and the Baltimore Street bridge was obtained with a flow combination of 20,000 cfs in Wills Creek and 93,000 cfs in North Branch, when stages in Wills Creek were controlled largely by the backwater from North Branch. It was found during tests of this reach that gradual transitions upstream and downstream of the Western Maryland Railroad bridge center pier will be required to eliminate waves forming at points of abrupt boundary changes.

Station 17+00 to station 54+00

24. Description. The Wills Creek channel from station 17+00 to station 54+00 was a low-velocity channel with paved side walls and unpaved bed, except that a short reach near the Baltimore and Ohio Railroad viaduct was paved and a concrete channel bed was provided from station 9+00 to station 22+00. The final plan tested for this reach included the following (see plate 6 and photographs 4 to 6):

a. Replacement of the Market Street bridge at station 24+75 (photograph 4) and the Valley Street bridge at station 39+90 (photograph 6) with single-span structures and side-wall transitions at the bridge abutments.

b. Conversion of the portion of the B & O RR. viaduct over Wills Creek to a two-span structure and modification of the piers (see photograph 5).

25. Results. Maximum water-surface elevations through the Wills Creek reach above station 17+00 were obtained during a flow of 50,000 cfs in Wills Creek and 63,000 cfs in North Branch (see plates 9 and 10 and photographs 7 to 9). Generally stages in this reach are not affected by backwater from North Branch except when the North Branch flow is several times that of Wills Creek, such as a flow of 20,000 cfs in Wills Creek and 93,000 cfs in North Branch. In the latter case, backwater from North Branch affects stages through the entire reach although these stages would be considerably lower than the maximum obtained with 50,000 cfs flow in Wills Creek. As can be seen from plate 9, water-surface

profiles through the Wills Creek reach between station 17+00 and station 54+00 were rather irregular, since they were affected by changes in channel slope, transitions at the Valley Street bridge, Market Street bridge, B & O RR. viaduct, and, to some extent, by conditions upstream and downstream of the reach.

Vicinity of Western Maryland City Junction Railroad bridge, stations 54+00 to 60+00

26. Description. The Western Maryland City Junction Railroad bridge is an existing structure crossing Wills Creek diagonally at approximately station 58+44. Plans for this reach were designed to lower the water-surface elevation by means of high-velocity flow so as to permit the safe passage of the design flood, and after the flow had passed safely underneath the bridge, to reduce the velocity below that producing scour in order to minimize the length of paved channel necessary downstream. The final plan tested for this reach is shown on plate 7 and included the following features:

a. Upstream extension of the existing pier with tapered nose and modification of the base of the pier.

b. Installation of a weir section between stations 57+60 and 57+35.

c. Construction of a stilling basin between stations 57+35 and 56+30.

d. Paving of channel and side walls as shown.

27. Results. The principal difficulty encountered in the development of plans for the City Junction bridge reach resulted from the large waves that formed either at the bridge pier or at the channel side-wall transitions (see photograph 10). Several plans were developed that provided the necessary clearance at the bridge but had to be abandoned because of objections from local interests or because of excessive cost. Tests of the final plan resulted in a clearance of at least 3 ft beneath both bridge spans and at the bridge seats. Tests also indicated that the stilling basin downstream operated satisfactorily for most flows. The hydraulic jump within the basin was rather sensitive to changes in the floor elevation of the basin as well as to changes in the alignment of the side

wall. With the channel side-wall slope of 1 on 1-1/2 extended into the basin, as in the final plan, a more uniform hydraulic jump occurred across the channel, and the maximum height of the jump was reduced without appreciably affecting velocities or water-surface elevations downstream for discharges of 30,000 cfs or more. Tests conducted with a 50-ft extension on the downstream end of the City Junction bridge pier eliminated the vortex and resulting fan-shaped wave below the pier and appeared to increase the stability of the jump within the basin; however, no appreciable change was noted in the velocities or water-surface elevations downstream.

Station 86+00 to station 60+00

28. Description. This reach included the upstream limit of improvements in Wills Creek. Plans for the improvement of flow conditions within this reach were designed to provide the necessary freeboard under the new U. S. Highway 40 bridge with consideration for requirements at the Western Maryland City Junction Railroad bridge downstream. The new U. S. Highway 40 bridge is a three-span structure crossing the axis of the stream at an angle of approximately 45 degrees. Plans tested in the model in the vicinity of the bridge included various upstream and downstream extensions to the bridge piers, guide vanes below the bridge to reduce superelevation of flow in the bend downstream, and various channel dimensions and slopes. The final plan tested in the model is shown on plate 8 and included the following features:

a. Natural channel bed with paved side walls along right bank from station 83+96.94 to station 82+25 and a hand-placed riprap transition section between station 82+25 and station 82+00.

b. Concrete-paved trapezoidal channel and splash walls from station 82+00 to station 60+00 with control section at station 80+42.79.

c. Upstream extensions of the U. S. Highway 40 bridge piers (see photograph 11).

d. Removal of the old masonry bridge at station 76+50.

29. Results. Flow conditions above station 60+00 are shown in photographs 12 and 13. The control section at station 80+42.79, the steep channel slope, and the upstream extensions on the highway bridge piers produced sufficient clearance under the Highway 40 bridge. High

velocities obtained beneath the bridge and an undulating jump occurred downstream. Some of the buildings on the right bank above the improvements were inundated (see photograph 13).

PART IV: DISCUSSION OF RESULTS

30. The model study for flood protection at Cumberland, Maryland, and Ridgeley, West Virginia, consisted of the investigation of a large number of plans involving changes in channel cross section, alignment, slope, and transitions, modifications to bridge abutments and piers, stilling basins, etc., before satisfactory conditions were obtained. The final plan resulted in the lowering of stages below the confluence of Wills Creek and North Branch by about 3 ft by increasing channel capacity, and in a relatively high-velocity channel through the lower reach of Wills Creek without the necessity for excessive wall heights through the city of Cumberland.

31. Operation of the plan in a satisfactory manner will depend to a large extent upon adequate maintenance, since the accumulation of debris at bridge piers or other channel obstructions could seriously affect stages in critical reaches.

Table 1

Water-surface Elevations in Feet Mean Sea Level

Gage* No.	Discharge NB 93,000 WC 20,000 113,000	Discharge NB 63,000 WC 50,000 113,000	Discharge NB 50,100 WC 38,200 88,300	Discharge NB 33,000 WC 27,000 60,000	Discharge NB 22,000 WC 18,000 40,000	Discharge NB 11,000 WC 9,000 20,000
			North Branch			
1	610.1	610.1	608.9	605.2	603.4	598.3
2	610.3	610.3	609.2	605.3	604.0	598.7
3	613.3	613.3	610.8	607.0	604.8	599.2
4	615.3	615.3	612.4	608.1	605.6	599.6
5	615.8	615.8	612.8	608.9	606.2	600.2
6	615.9	616.0	613.1	609.0	606.2	600.5
7	617.0	617.0	614.1	609.8	606.8	601.0
8	618.0	617.8	614.9	610.2	606.7	601.1
9	618.9	618.9	616.0	611.9	608.3	602.1
10	619.3	619.4	616.7	612.7	609.7	603.3
11	619.2	619.3	616.6	612.7	609.2	602.9
12	619.3	619.3	616.7	613.4	610.1	604.0
13	619.8	619.8	617.1	613.6	610.2	604.1
14	621.4	621.4	618.3	614.5	610.9	604.4
18	622.4	622.5	619.5	615.6	612.1	605.7
19	622.9	622.9	619.9	616.0	612.3	606.0
20	623.8	623.8	620.8	616.8	613.1	606.8
21	625.2	625.3	622.2	618.2	614.3	608.2
22	625.1	625.3	622.3	618.2	614.4	608.2
23	625.0	625.4	622.2	618.2	614.3	608.2
24	629.9	627.8	624.6	620.8	618.7	616.3
25	628.9	627.5	624.3	620.7	618.8	616.3
26	632.5	629.3	625.9	621.7	619.4	616.6
27	634.0	630.2	627.0	622.6	619.9	616.8
28	634.7	630.7	627.5	623.2	620.3	617.1
			Wills Creek			
3	635.3	642.7	640.0			
4	634.8	642.7	640.1			
5	634.4	640.3	638.3			
6	636.1	643.9	641.0			
7	633.2	641.0	638.3			
8	632.9	639.1	636.6			
9	635.3	643.1	640.0			
10	632.9	640.3	637.2			
11	635.5	643.3	640.1			
12	631.3	638.2	635.8			
13	633.7	641.3	638.8			
14	631.7	639.5	636.7			
15	631.1	637.6	634.8			
16	630.7	638.0	635.4			

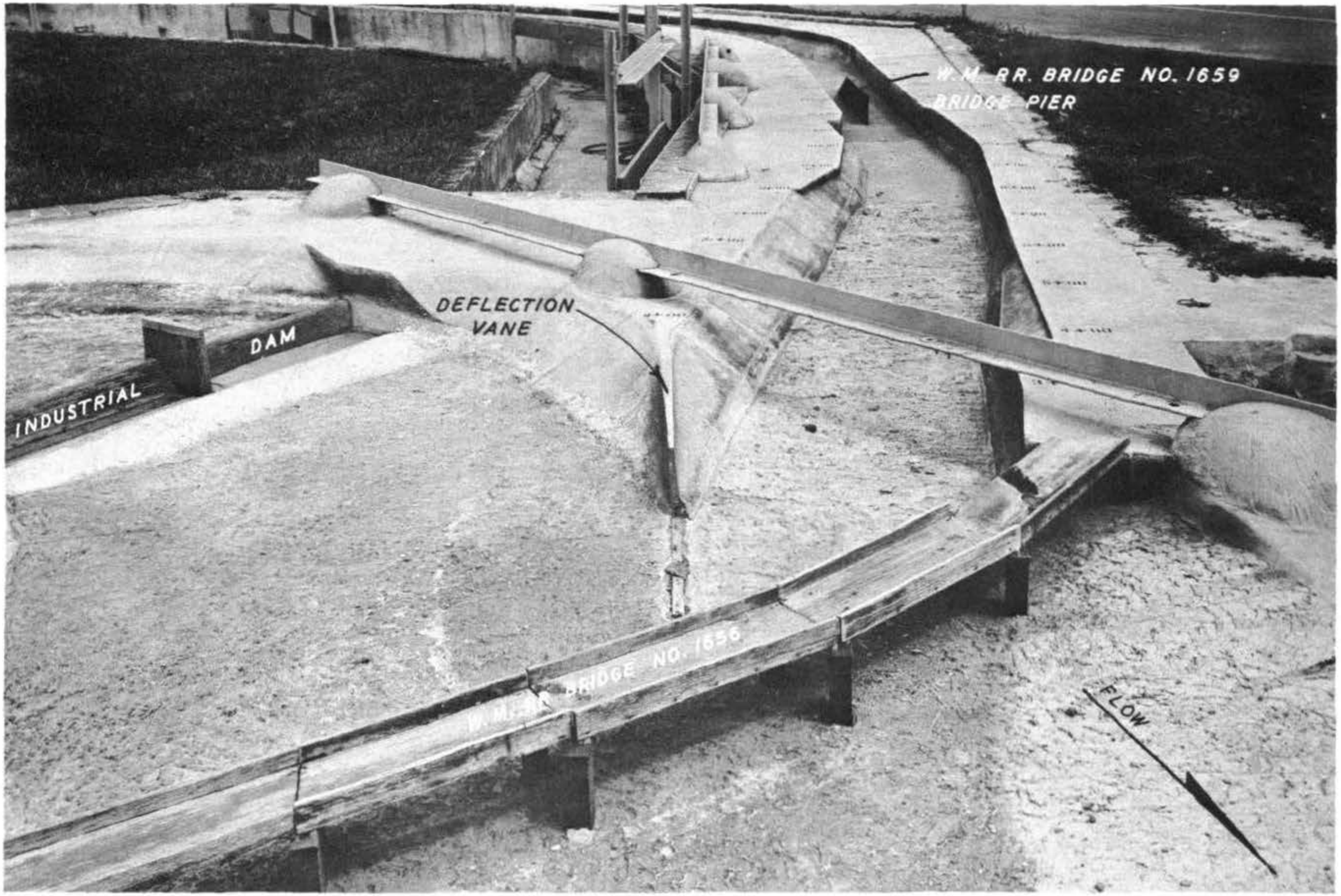
(Continued)

* See plate 1 for gage locations.

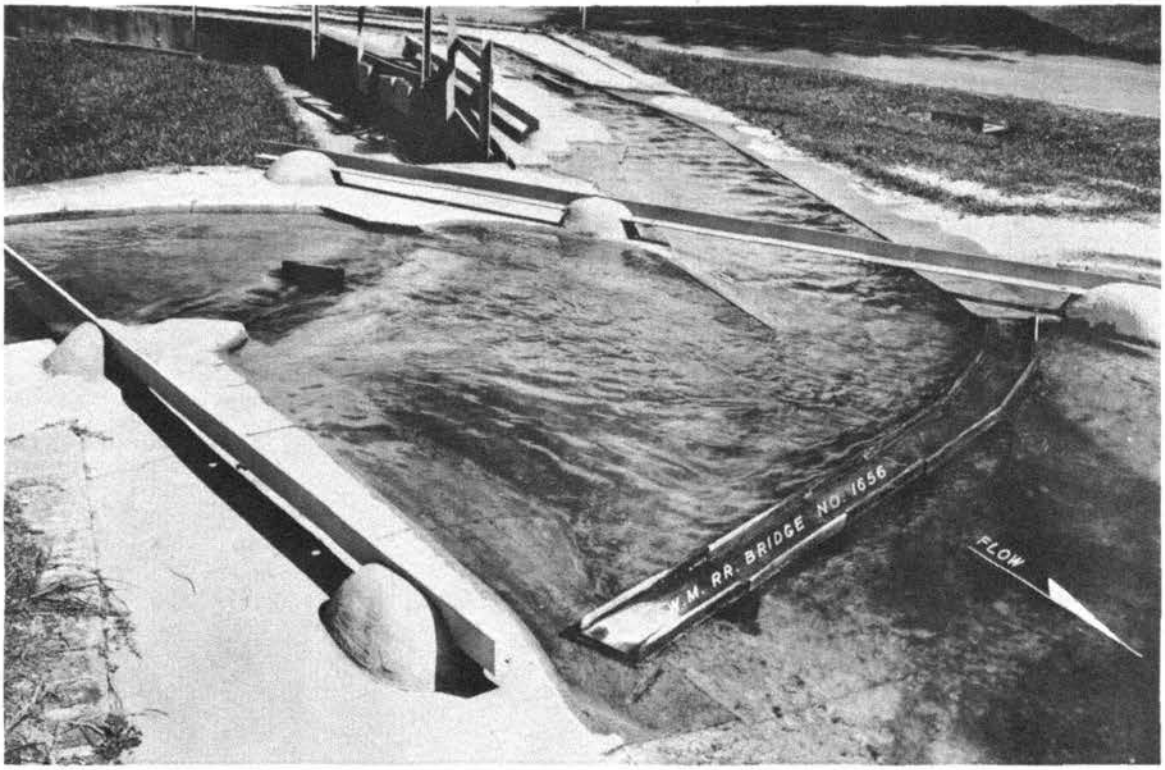
Table 1 (Continued)

Gage No.*	Discharge NB 93,000 WC 20,000 113,000	Discharge NB 63,000 WC 50,000 113,000	Discharge NB 50,100 WC 38,200 88,300	Discharge NB 33,000 WC 27,000 60,000	Discharge NB 22,000 WC 18,000 40,000	Discharge NB 11,000 WC 9,000 20,000
	Wills Creek (Continued)					
21	629.2	636.0	633.4	630.5	631.0	628.1
23	629.3	637.1	633.8	631.1	628.5	625.4
25	627.5	634.3	632.0	630.0	628.0	625.1
27	624.7	630.2	628.1	626.3	624.0	621.5
28	625.3	631.9	629.0	626.8	624.5	621.9
29	628.2	627.3	634.2	631.0	627.2	623.2
30	625.8	631.3	628.7	624.4	621.5	621.2
31	627.2	632.5	629.4	626.6	625.0	621.4
32	626.9	633.8	630.5	627.4	624.8	620.8
33	627.0	634.0	630.8	627.6	624.6	620.6
34	626.6	632.9	629.7	626.4	623.4	619.3
35	626.3	631.9	628.2	625.0	622.1	618.3
36	626.2	631.7	627.7	624.4	621.4	617.6
37	626.1	631.1	627.0	623.8	620.8	616.7
38	625.9	629.6	625.6	622.8	620.2	616.1
39	626.0	630.4	626.3	622.7	619.7	615.7
40	626.0	630.7	626.3	622.4	619.2	615.2
41	626.1	631.1	626.7	622.6	619.1	615.0
42	625.9	628.8	624.3	620.4	616.4	611.6
43	625.6	628.8	624.0	619.5	615.9	611.4
44	626.1	630.7	625.3	620.7	616.4	611.9
45	626.0	629.6	624.8	620.5	616.8	612.2
46	625.9	628.8	624.0	619.4	615.6	610.8
47	625.6	627.5	623.2	619.0	615.2	610.1
48	625.6	627.4	622.9	618.5	614.7	609.0
49	625.5	627.2	622.6	618.4	614.3	607.4
50	625.5	626.9	622.6	618.2	614.4	608.5
51	625.4	626.1	622.3	618.4	614.5	608.7
52	625.1	624.8	621.1	617.6	614.1	608.7
53	625.3	624.2	621.1	617.6	614.3	608.6
54	625.2	617.8	619.9	617.2	613.9	608.6
55	625.1	617.2	620.3	617.2	614.1	608.6
56	625.4	624.5	622.0	618.2	614.6	608.9
57	625.6	625.5	622.6	618.5	614.8	608.9
58	625.6	626.1	622.7	618.7	614.9	608.9
59	625.7	626.3	622.9	618.8	614.9	608.8
60	625.7	626.2	622.9	618.7	614.8	608.7
61	625.8	626.2	622.9	618.7	614.9	608.7

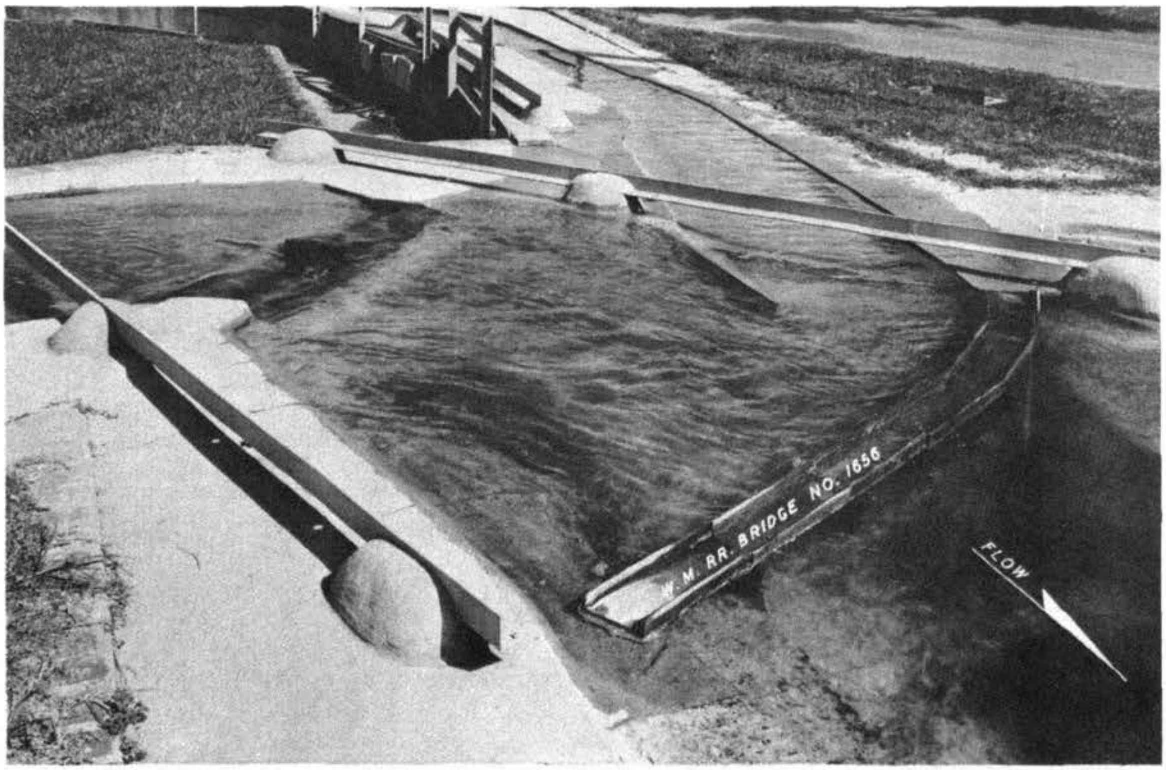
* See plate 1 for gage locations.



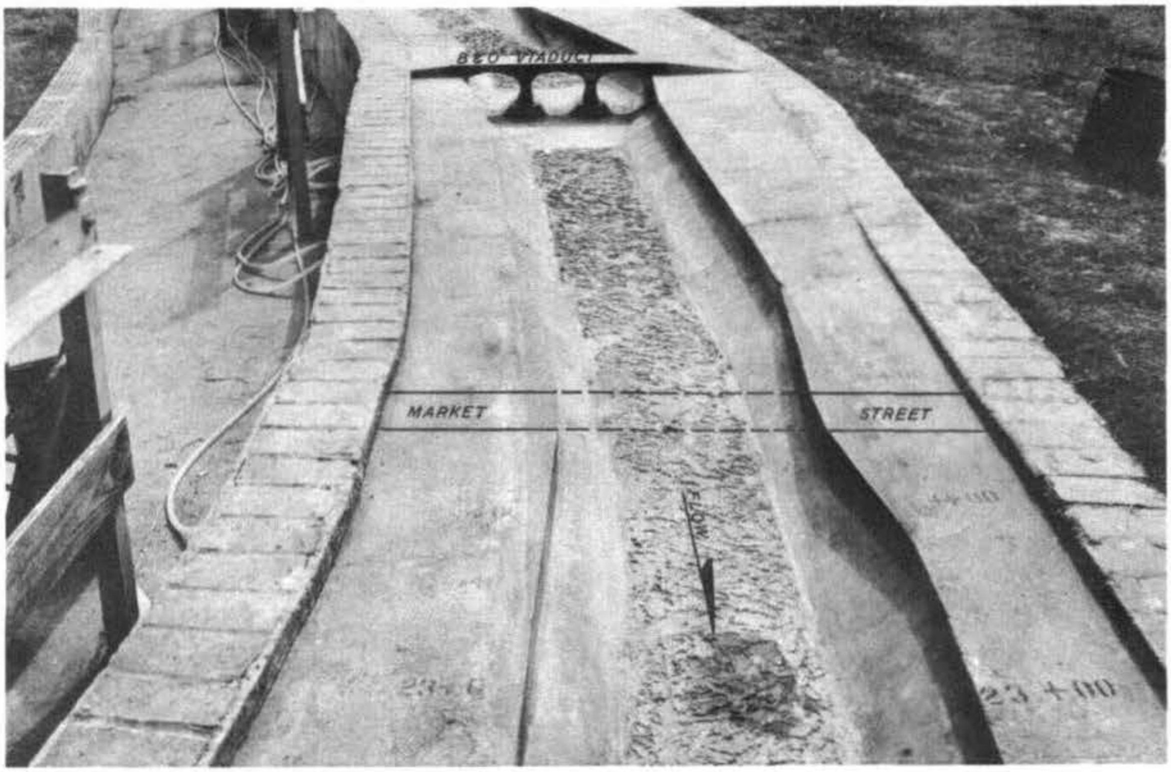
Photograph 1. Proposed channel improvements at confluence of North Branch of Potomac River and Wills Creek



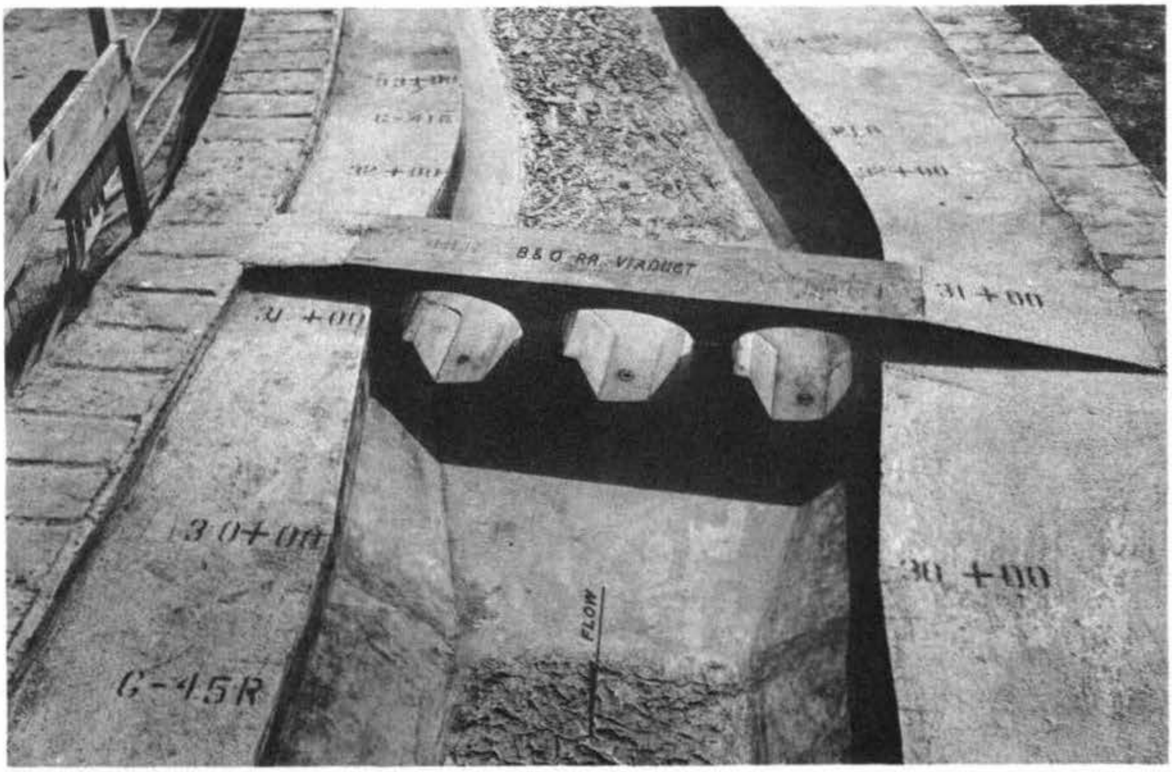
Photograph 2. Flow conditions at confluence with discharges of:
North Branch, 63,000 cfs; Wills Creek, 50,000 cfs



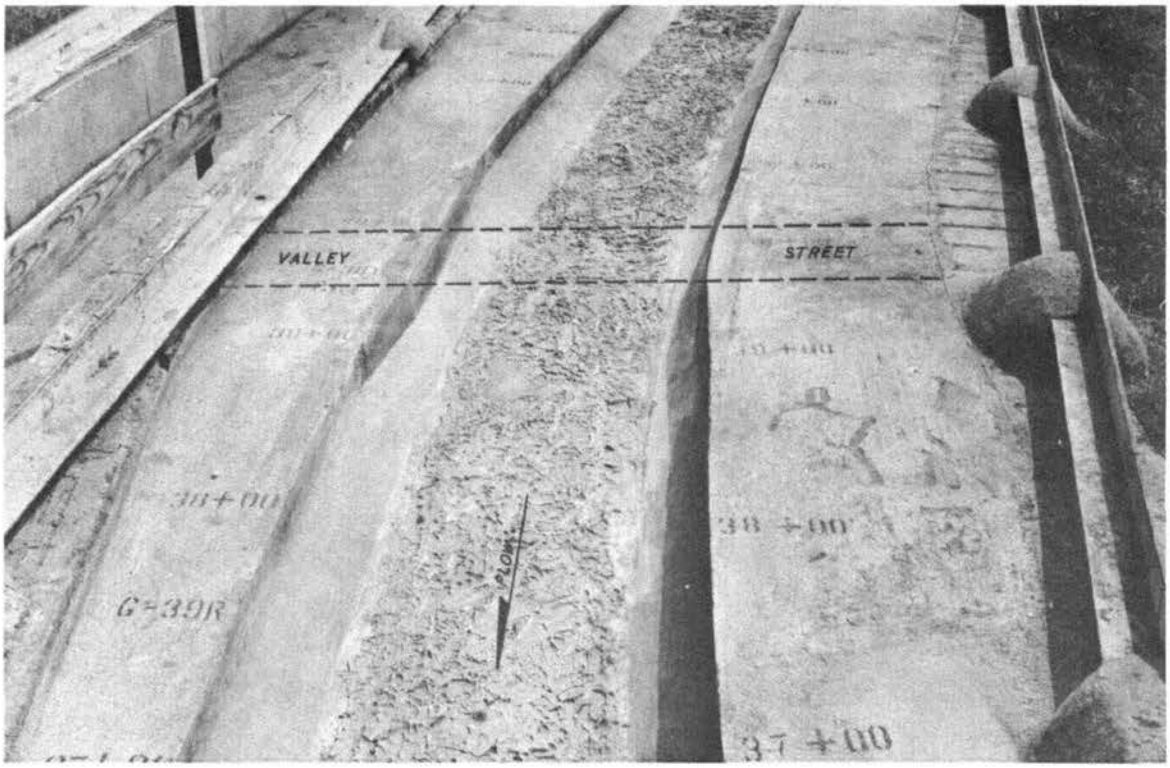
Photograph 3. Flow conditions at confluence with discharges of:
North Branch, 93,000 cfs; Wills Creek, 20,000 cfs



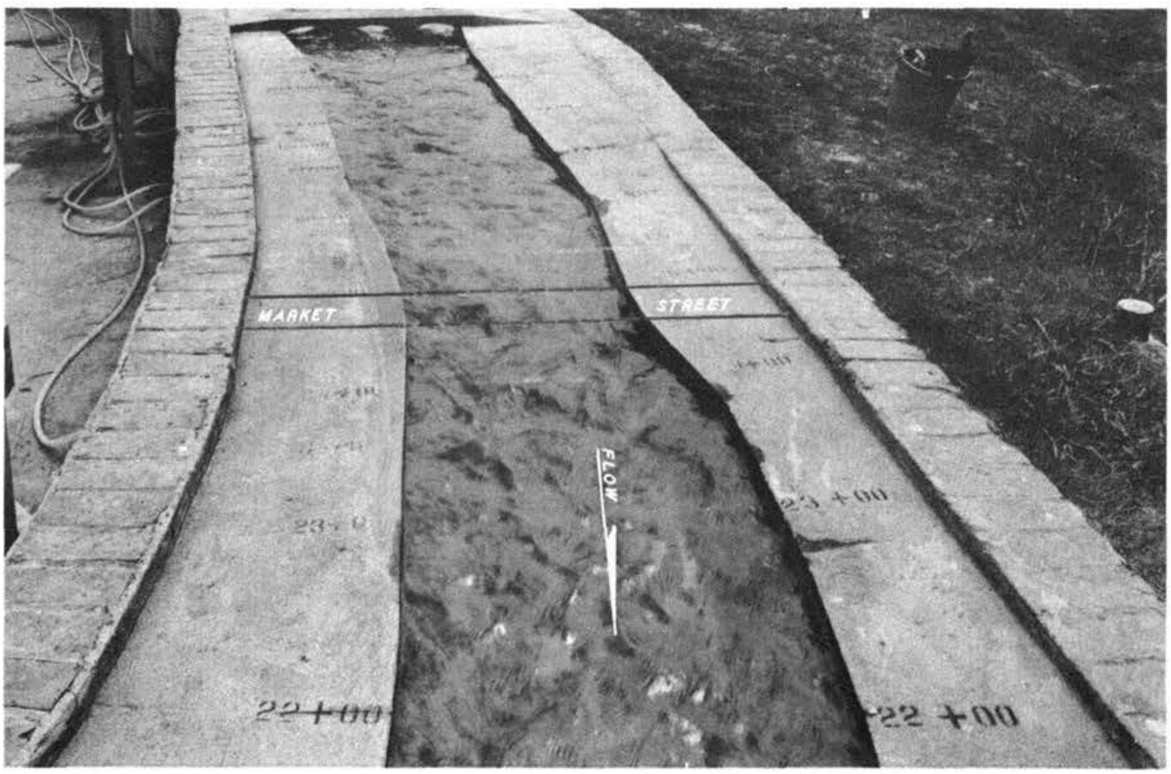
Photograph 4. Improved channel in Wills Creek in
vicinity of Market Street bridge



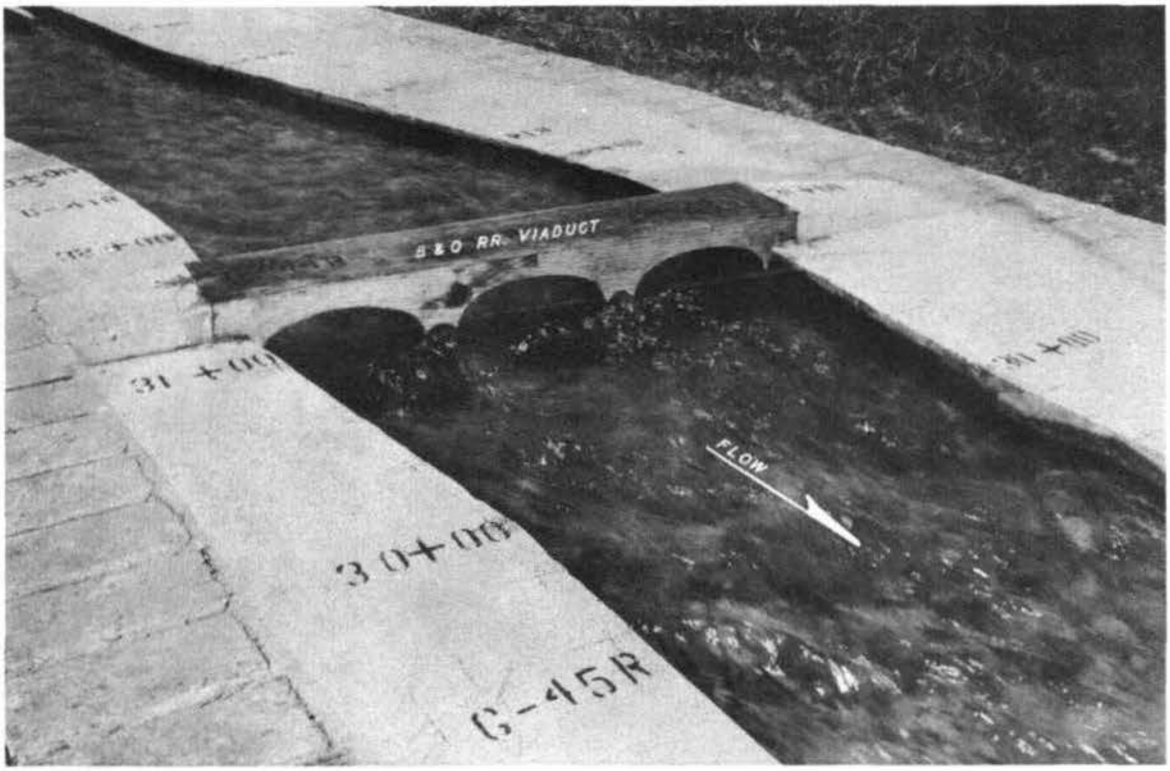
Photograph 5. Modification of Baltimore and Ohio Railroad viaduct
and channel transitions in Wills Creek



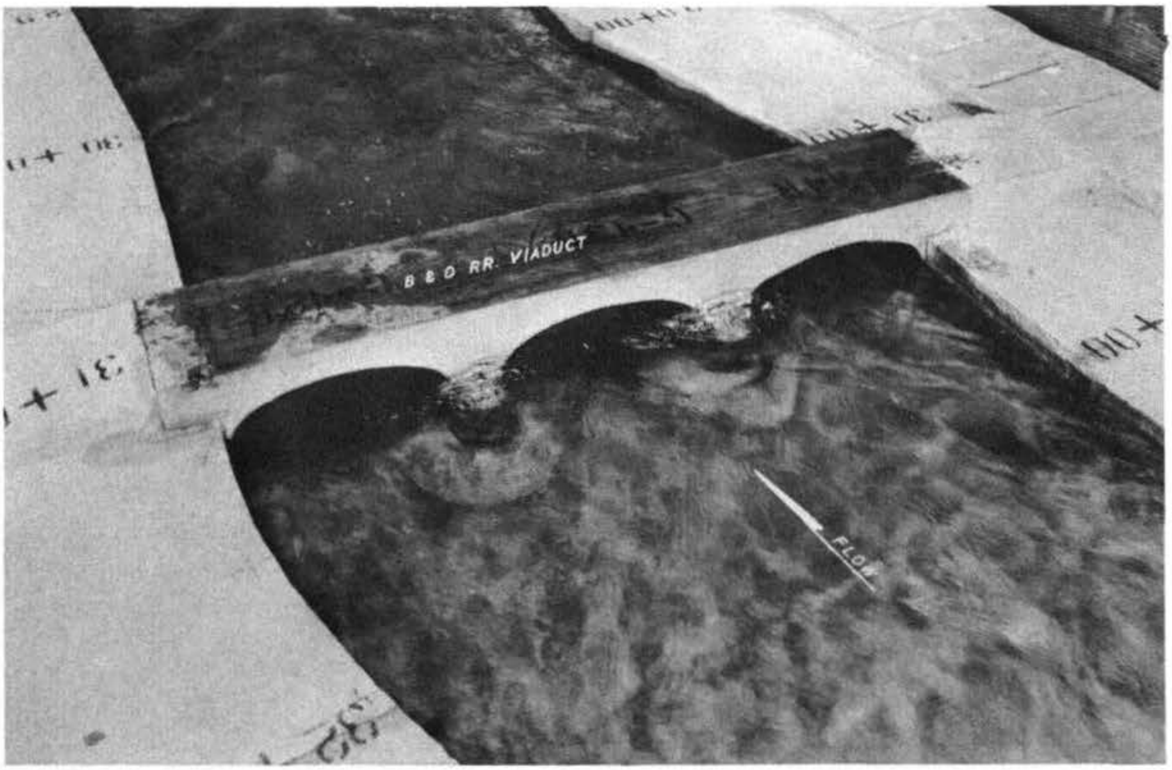
Photograph 6. Improved channel and channel transition in vicinity of Valley Street bridge in Wills Creek



Photograph 7. Flow conditions in vicinity of Market Street bridge. Discharge: North Branch, 63,000 cfs; Wills Creek, 50,000 cfs

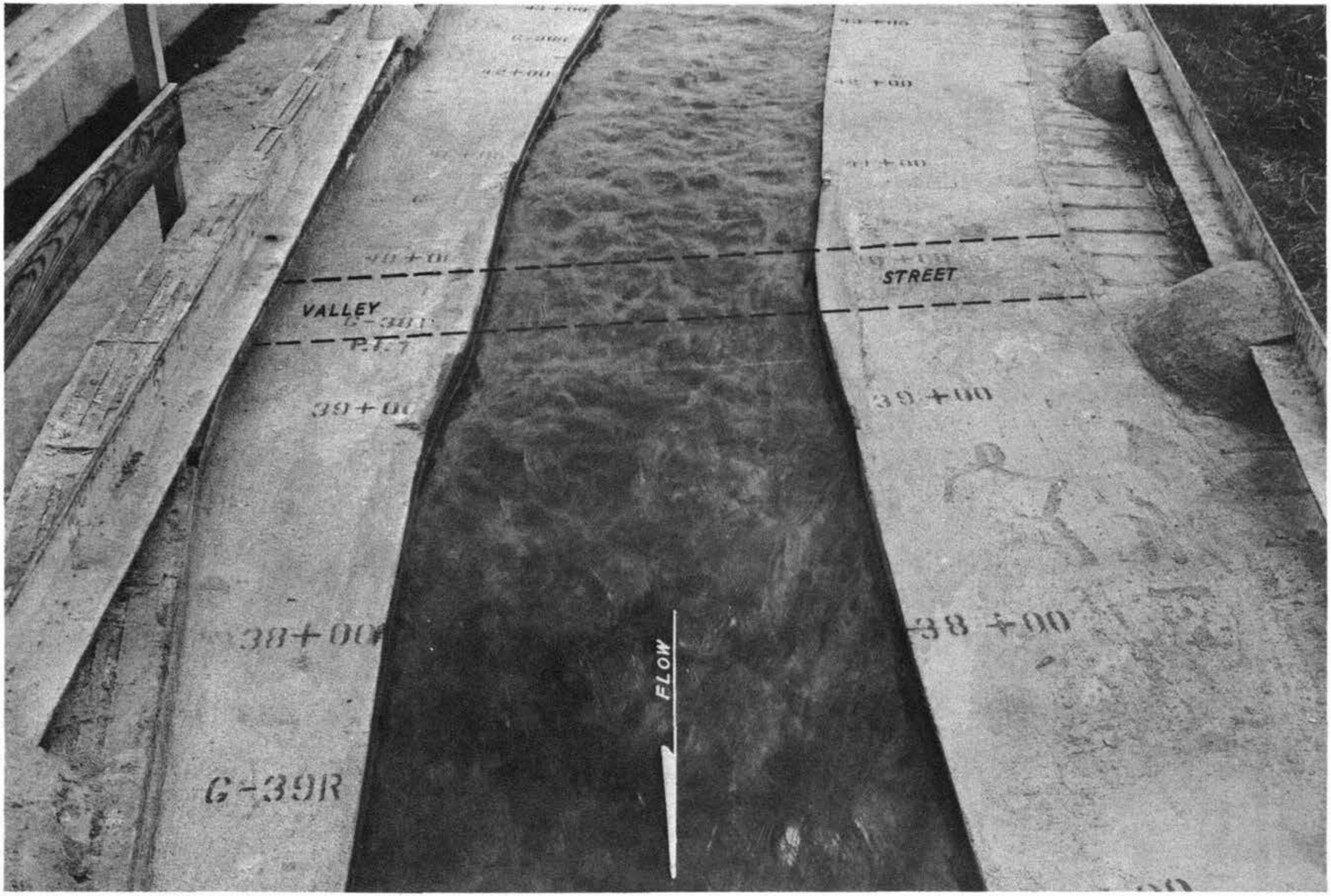


Upstream view



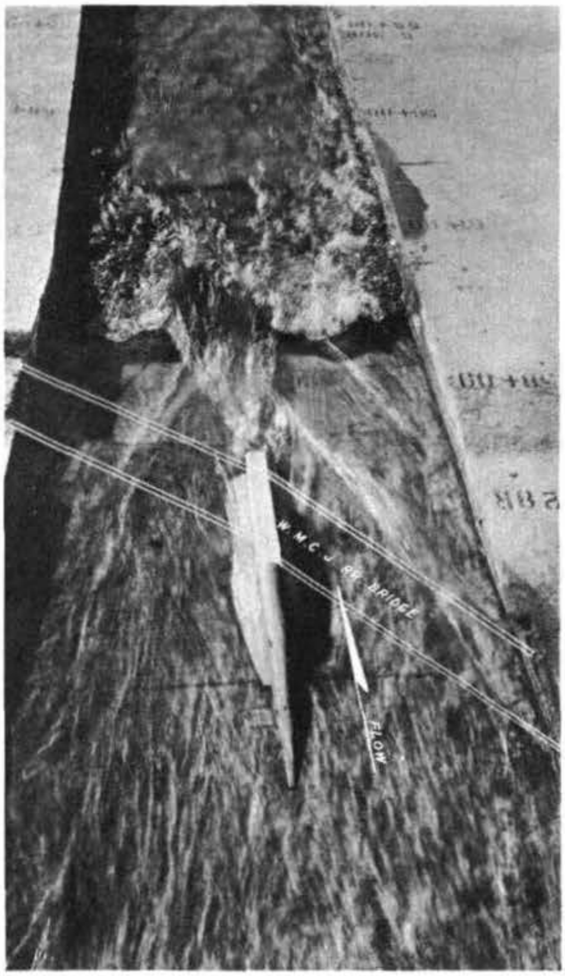
Downstream view

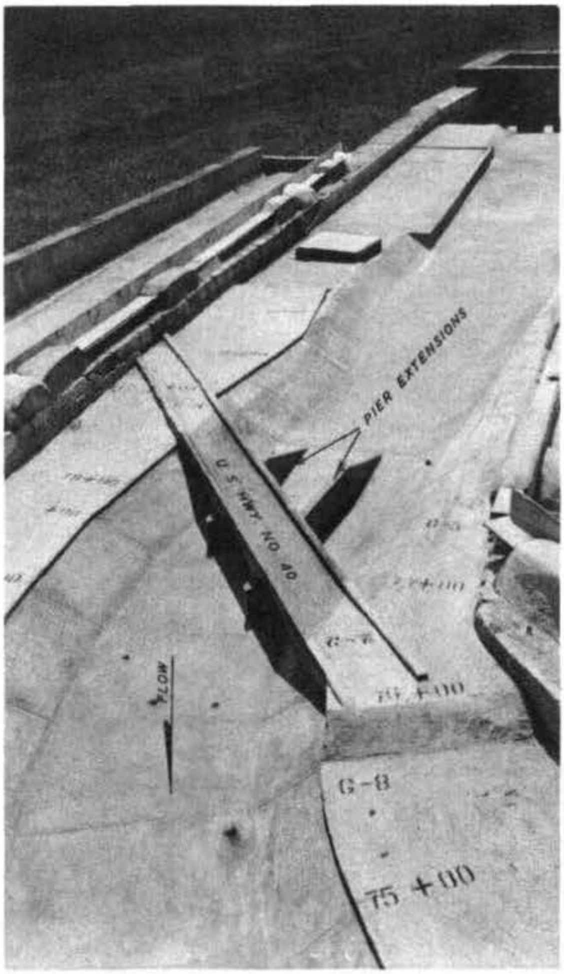
Photograph 8. Flow conditions in vicinity of Baltimore and Ohio Railroad viaduct. Discharge: North Branch, 63,000 cfs; Wills Creek, 50,000 cfs



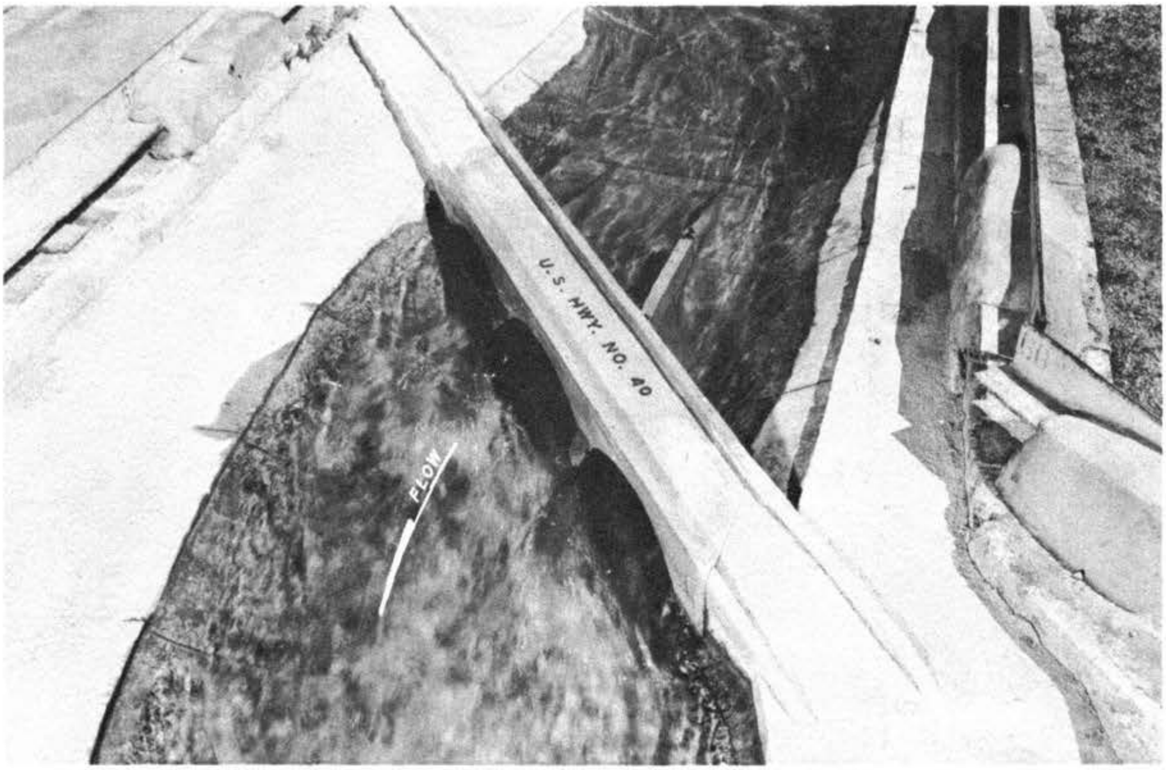
Photograph 9. Flow conditions at the Valley Street bridge. Discharge: North Branch, 63,000 cfs; Wills Creek, 50,000 cfs

Photograph 10. Flow conditions in vicinity of Western Maryland City Junction Railroad bridge. Discharge: Wills Creek, 50,000 cfs





Photograph 11. Channel improvements in the vicinity of U. S. Highway 40 bridge

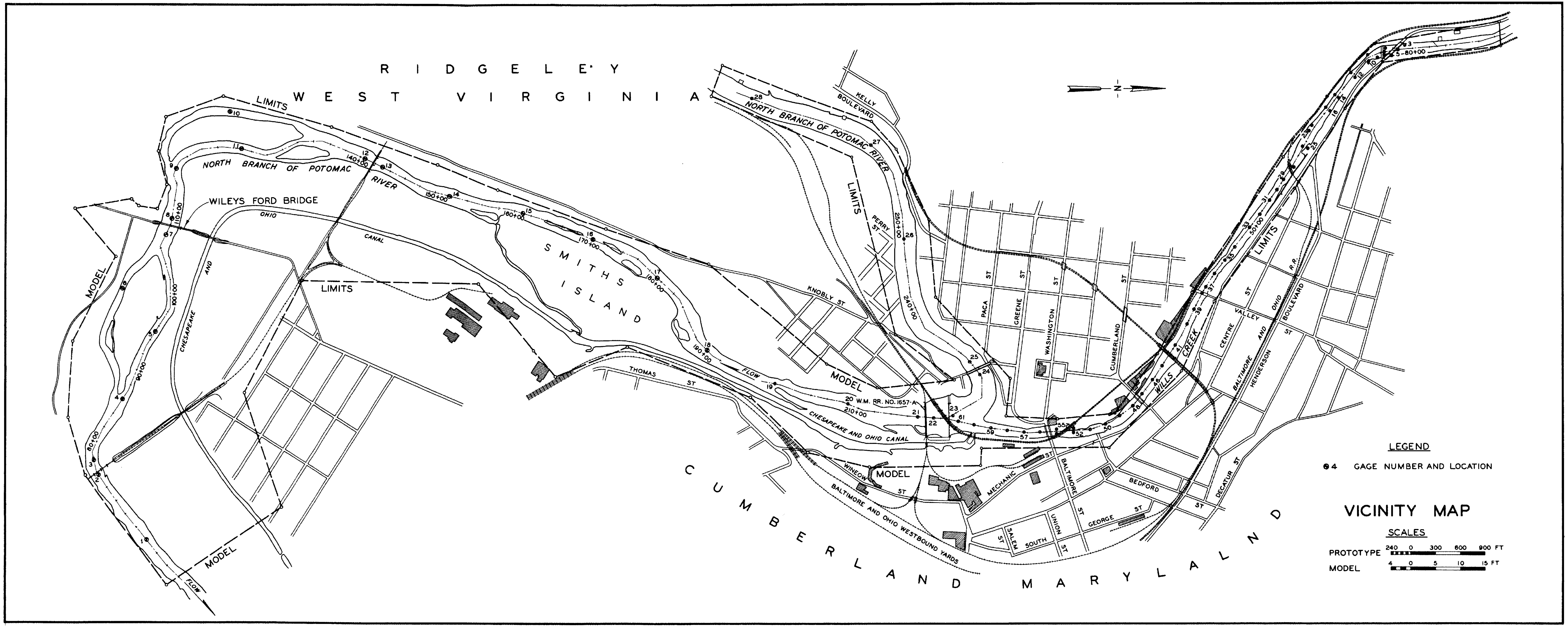


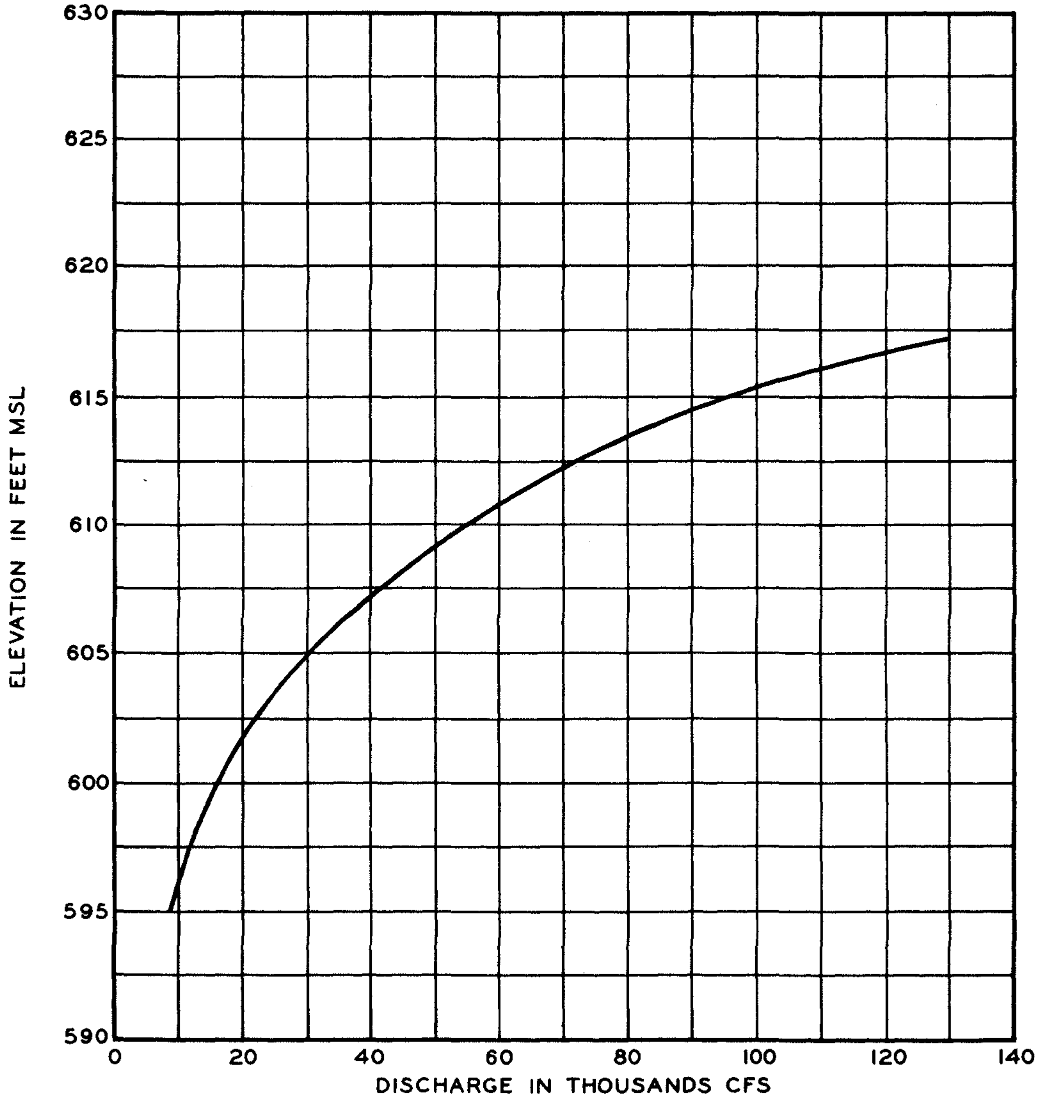
Upstream view

Downstream view

Photograph 12. Flow conditions in vicinity of U. S. Highway 40 bridge.
Discharge: Wills Creek, 50,000 cfs; North Branch, 63,000 cfs

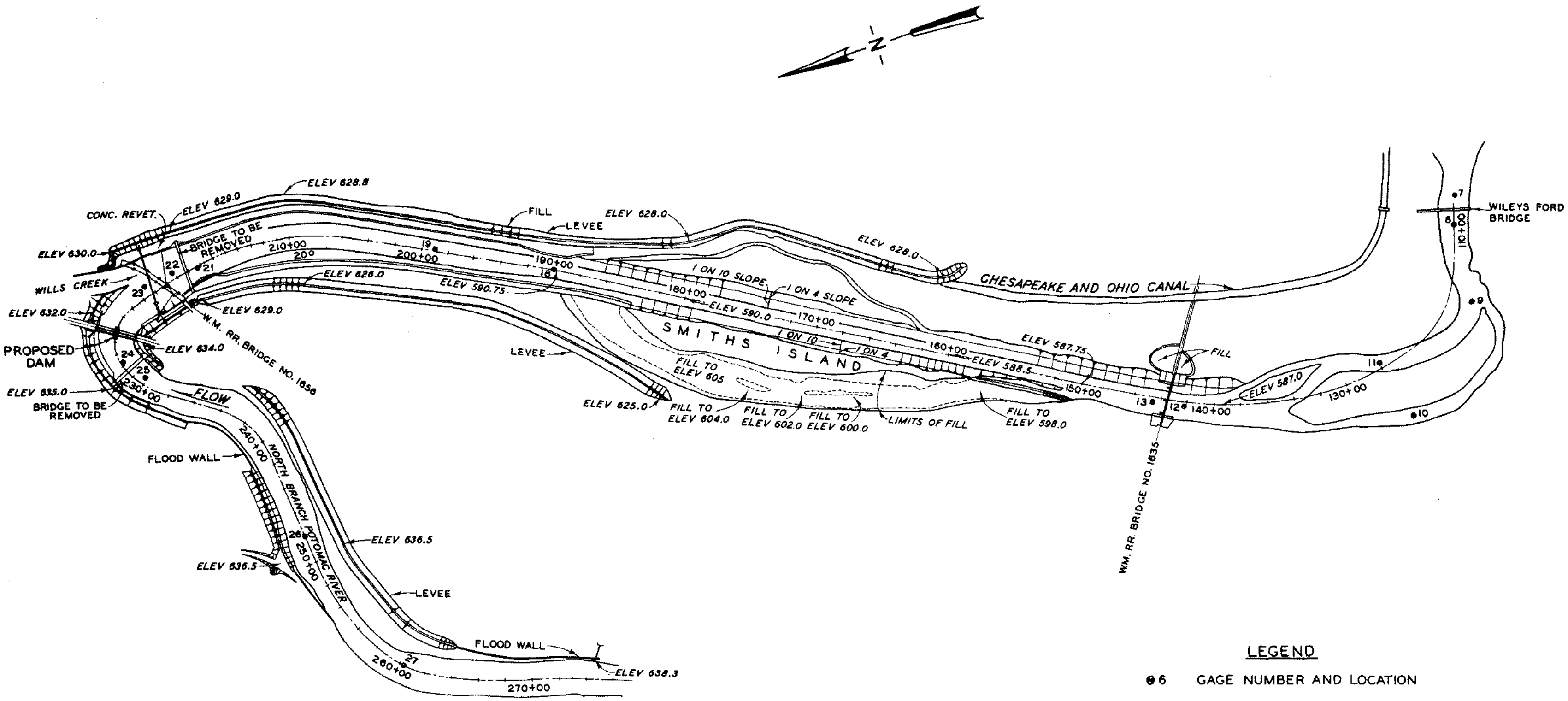
Photograph 13. Flow conditions above U. S. Highway 40 bridge (note flooding of right overbank).
Discharge: Wills Creek, 50,000 cfs; North Branch, 63,000 cfs


RIDGELEY
WEST VIRGINIA
CUMBERLAND MARYLAND
NORTH BRANCH OF POTOMAC RIVER
SMITHS ISLAND
WILEYS FORD BRIDGE
CHESAPEAKE AND OHIO CANAL
LIMITS
MODEL
FLOW
WILLS CREEK
BALTIMORE AND OHIO WESTBOUND YARDS
W.M. RR. NO. 1657-A
LEGEND
GAGE NUMBER AND LOCATION
VICINITY MAP
SCALES
PROTOTYPE 240 0 300 600 900 FT
MODEL 4 0 5 10 15 FT



DISCHARGE RATING CURVE
NORTH BRANCH - POTOMAC RIVER
WILEYS FORD BRIDGE

PLATE 3



LEGEND

● 6 GAGE NUMBER AND LOCATION

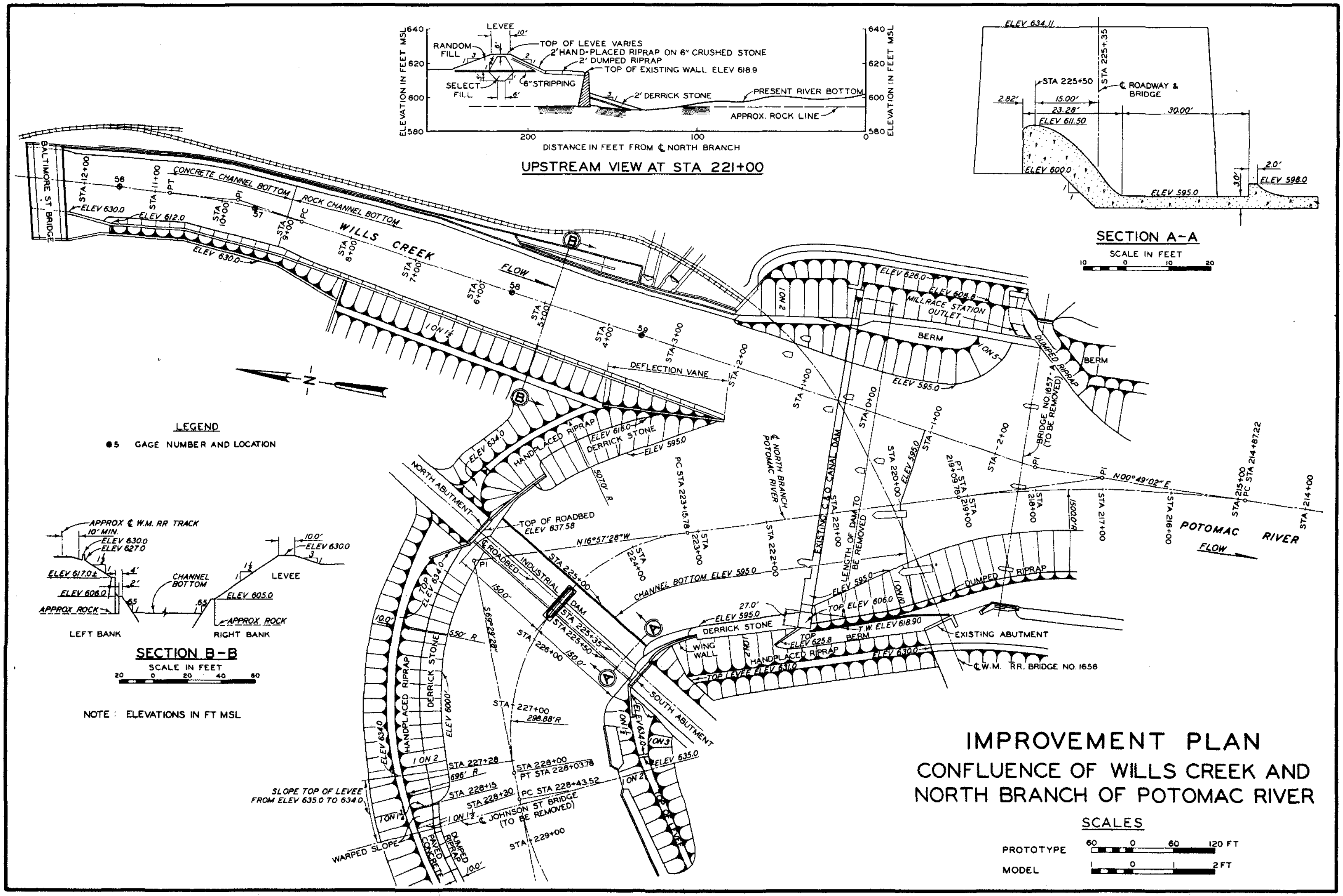
NOTE: ELEVATIONS IN FEET MSL

IMPROVEMENT PLAN
NORTH BRANCH OF POTOMAC RIVER

SCALES

PROTOTYPE 240 0 300 600 900 FT

MODEL 4 0 5 10 15 FT

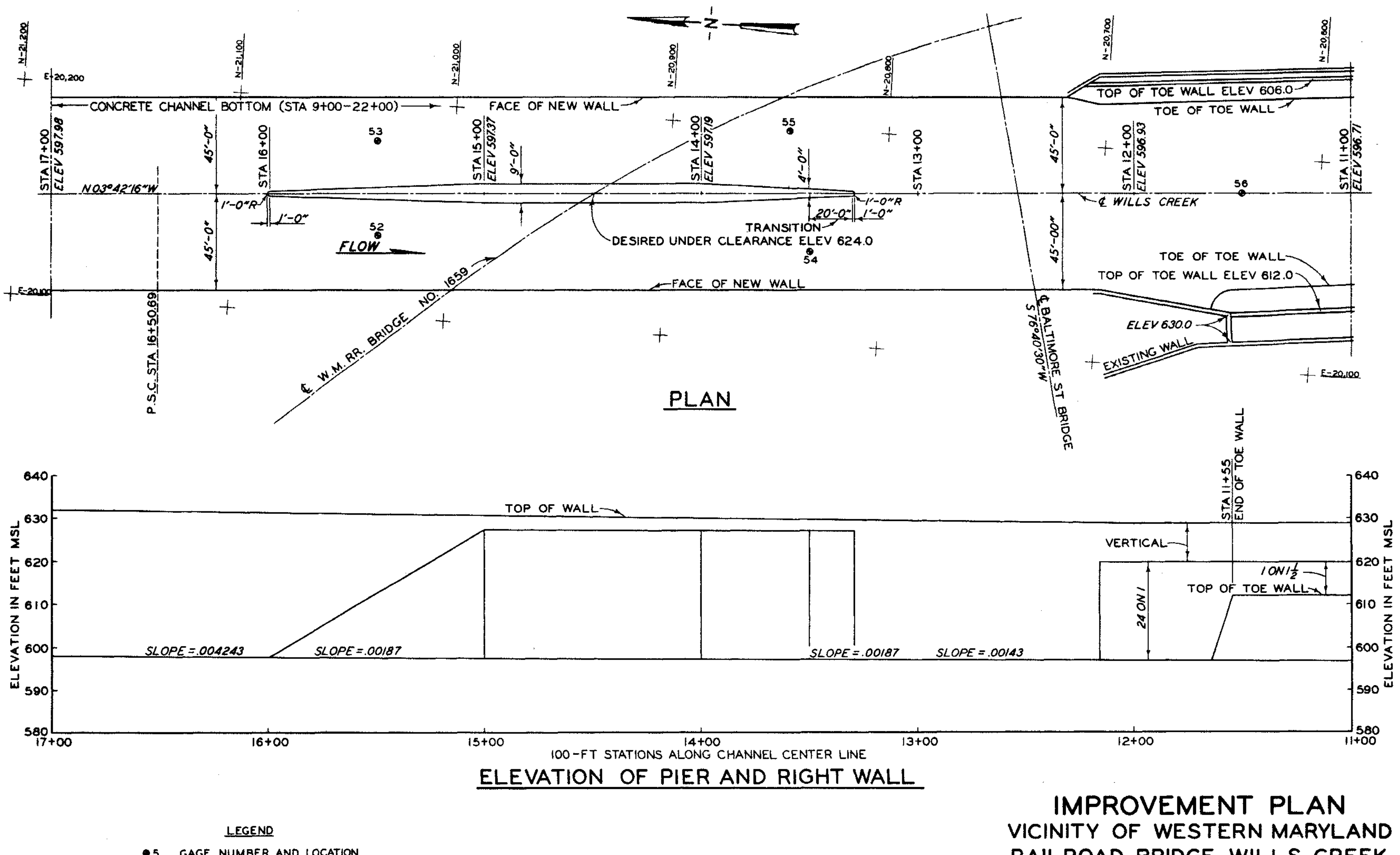


IMPROVEMENT PLAN

CONFLUENCE OF WILLS CREEK AND NORTH BRANCH OF POTOMAC RIVER

PLATE 4

PLATE 5

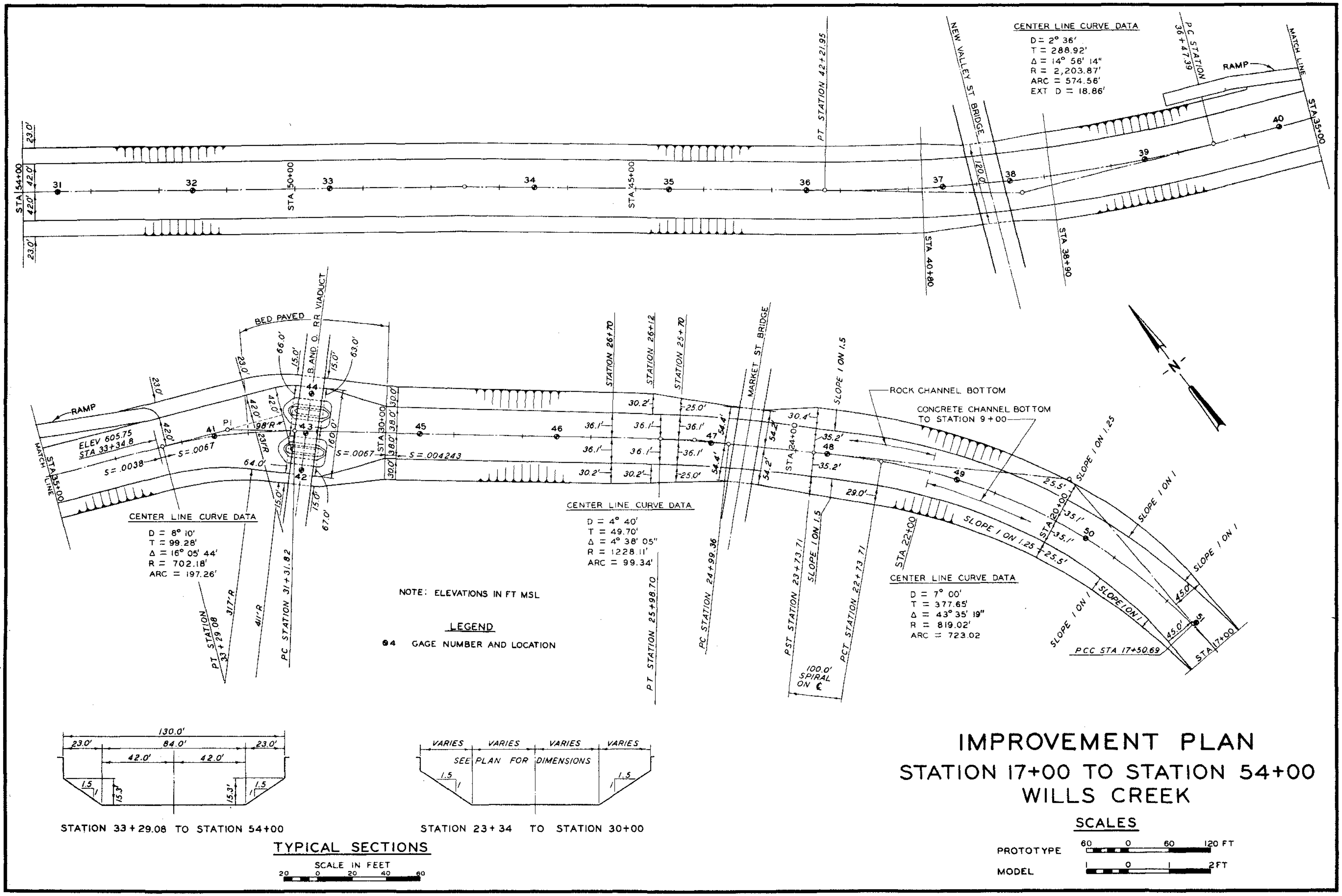


IMPROVEMENT PLAN
VICINITY OF WESTERN MARYLAND RAILROAD BRIDGE, WILLS CREEK

SCALES

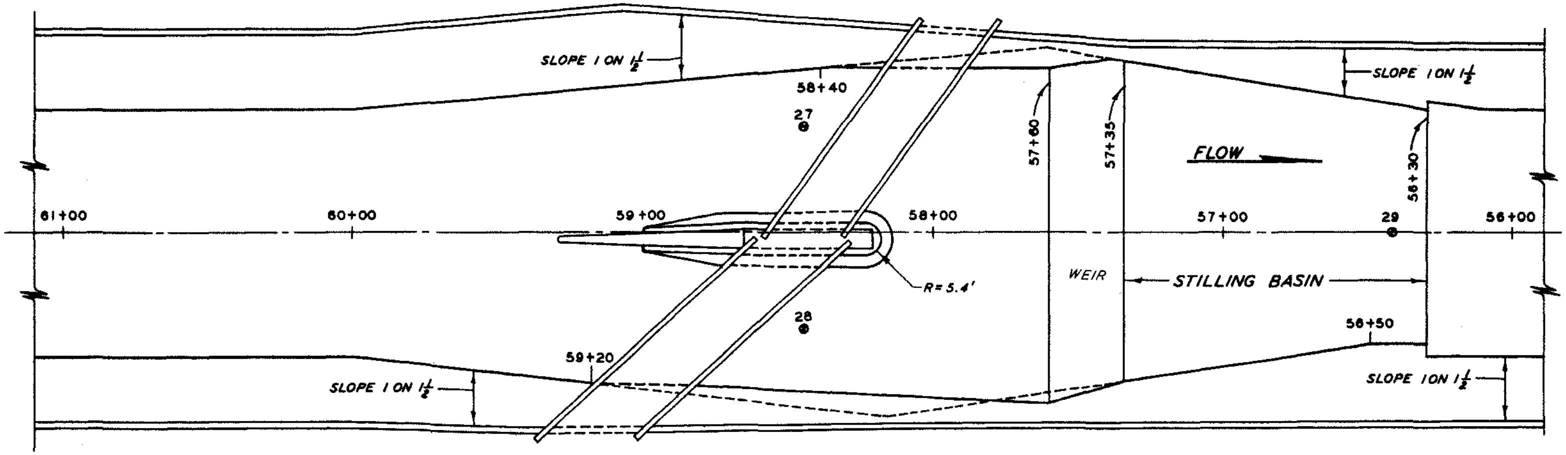
PROTOTYPE 30 0 30 60 FT

MODEL 0.5 0 0.5 1.0 FT

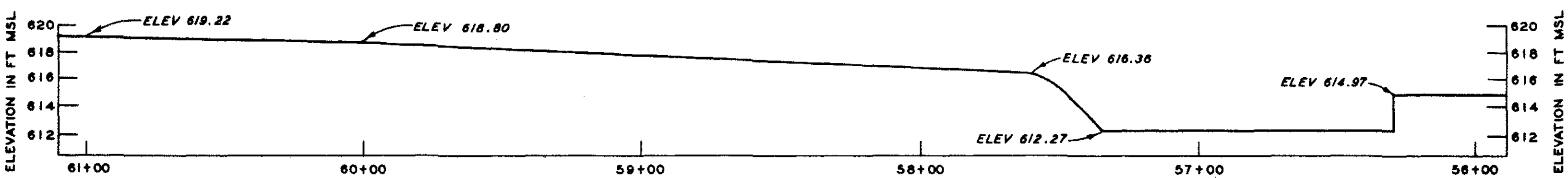


CENTER LINE CURVE DATA
D = 2° 36'
T = 288.92'
Δ = 14° 56' 14"
R = 2,203.87'
ARC = 574.56'
EXT D = 18.86'
NEW VALLEY ST BRIDGE
PT STATION 42+21.95
PC STATION 36+47.39
MATCH LINE
RAMP
STA 54+00
STA 50+00
STA 45+00
STA 40+80
STA 38+90
STA 35+00
BED PAVED
B AND O RR VIADUCT
STATION 26+70
STATION 26+12
STATION 25+70
MARKET ST BRIDGE
ROCK CHANNEL BOTTOM
CONCRETE CHANNEL BOTTOM TO STATION 9+00
ELEV 605.75
STA 33+34.8
S = .0038
S = .0067
S = .004243
STA 30+00
STA 24+00
STA 22+00
STA 20+00
STA 17+00
CENTER LINE CURVE DATA
D = 8° 10'
T = 99.28'
Δ = 16° 05' 44'
R = 702.18'
ARC = 197.26'
CENTER LINE CURVE DATA
D = 4° 40'
T = 49.70'
Δ = 4° 38' 05"
R = 1228.11'
ARC = 99.34'
CENTER LINE CURVE DATA
D = 7° 00'
T = 377.65'
Δ = 43° 35' 19"
R = 819.02'
ARC = 723.02
PT STATION 33+29.08
PC STATION 31+31.82
PT STATION 25+98.70
PC STATION 24+99.36
PST STATION 23+73.71
PCT STATION 22+73.71
100.0' SPIRAL ON ℄
PCC STA 17+50.69
SLOPE 1 ON 1.5
SLOPE 1 ON 1.25
SLOPE 1 ON 1
NOTE: ELEVATIONS IN FT MSL
LEGEND
⊗4 GAGE NUMBER AND LOCATION
STATION 33+29.08 TO STATION 54+00
STATION 23+34 TO STATION 30+00
SEE PLAN FOR DIMENSIONS
TYPICAL SECTIONS
SCALE IN FEET
IMPROVEMENT PLAN
STATION 17+00 TO STATION 54+00
WILLS CREEK
SCALES
PROTOTYPE
MODEL

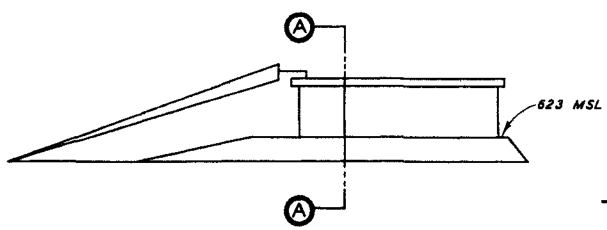
PLATE 6



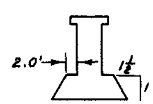
PLAN



CHANNEL CENTER LINE PROFILE



ELEVATION



SECTION A-A

LEGEND

● 2 GAGE NUMBER AND LOCATION

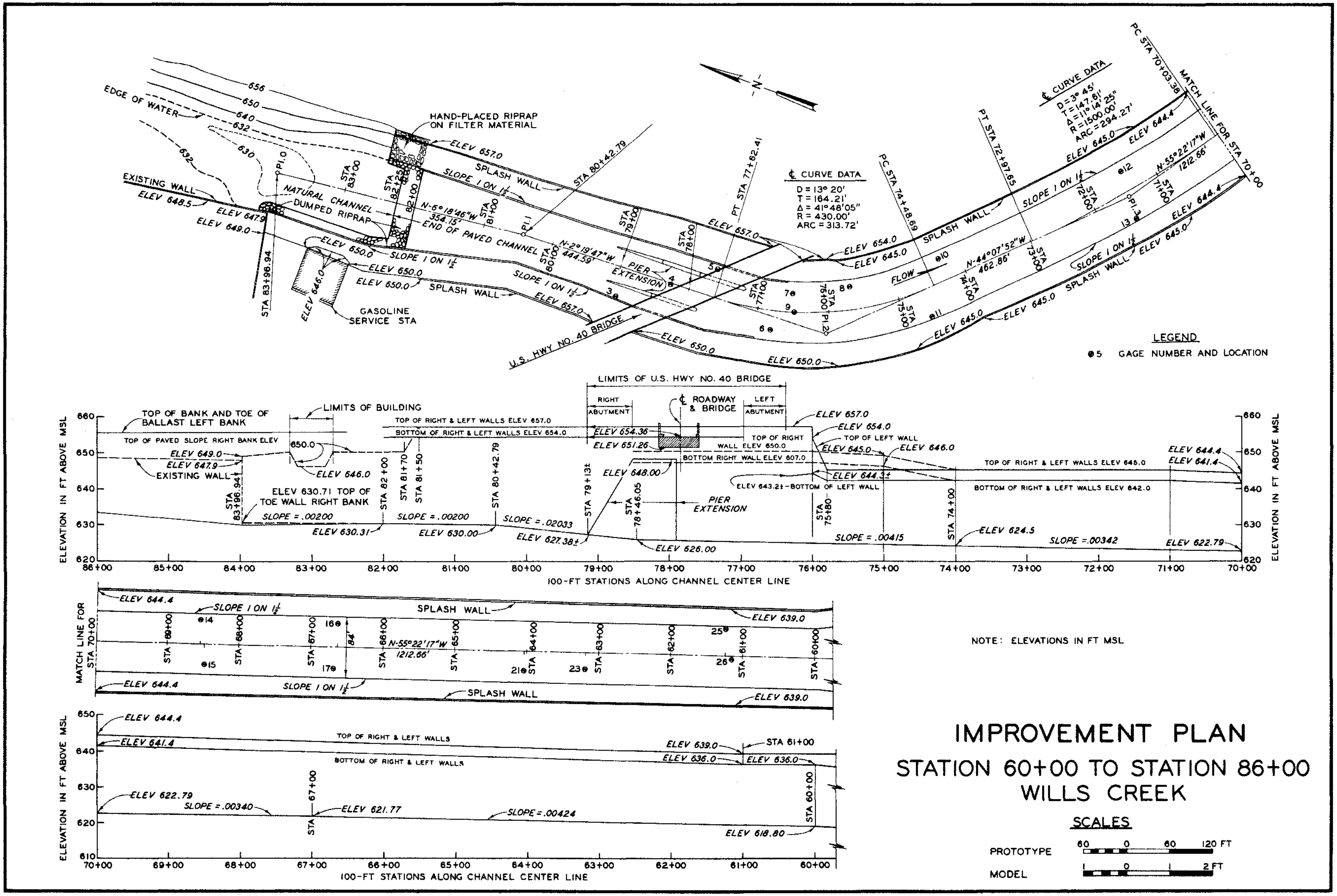
IMPROVEMENT PLAN

VICINITY W.M.C.J. RAILROAD BRIDGE
WILLS CREEK

SCALES

PROTOTYPE 60 0 60 120 FT

MODEL 1 0 1 2 FT

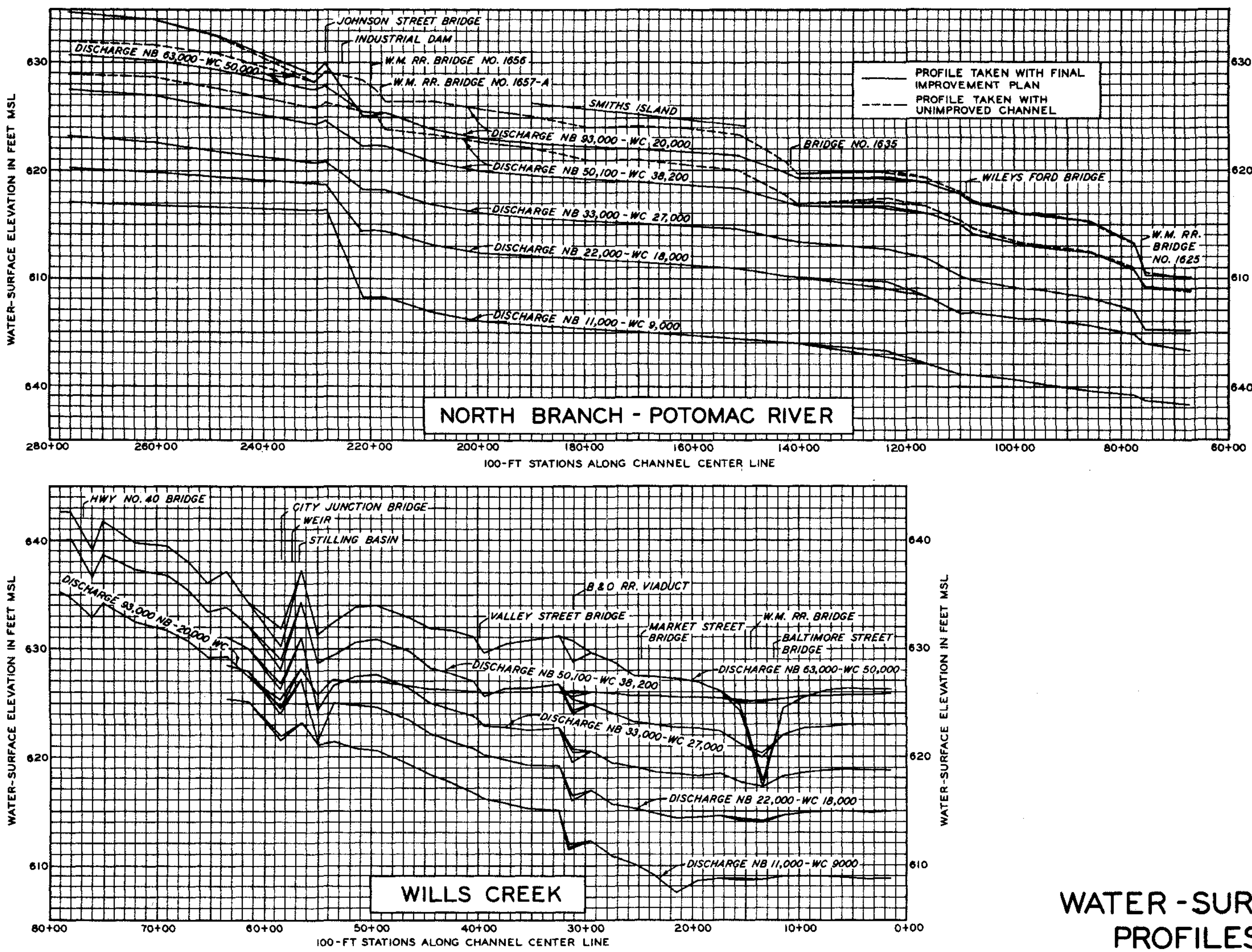


IMPROVEMENT PLAN

STATION 60+00 TO STATION 86+00 WILLS CREEK

PLATE 8

PLATE 9



WATER - SURFACE PROFILES

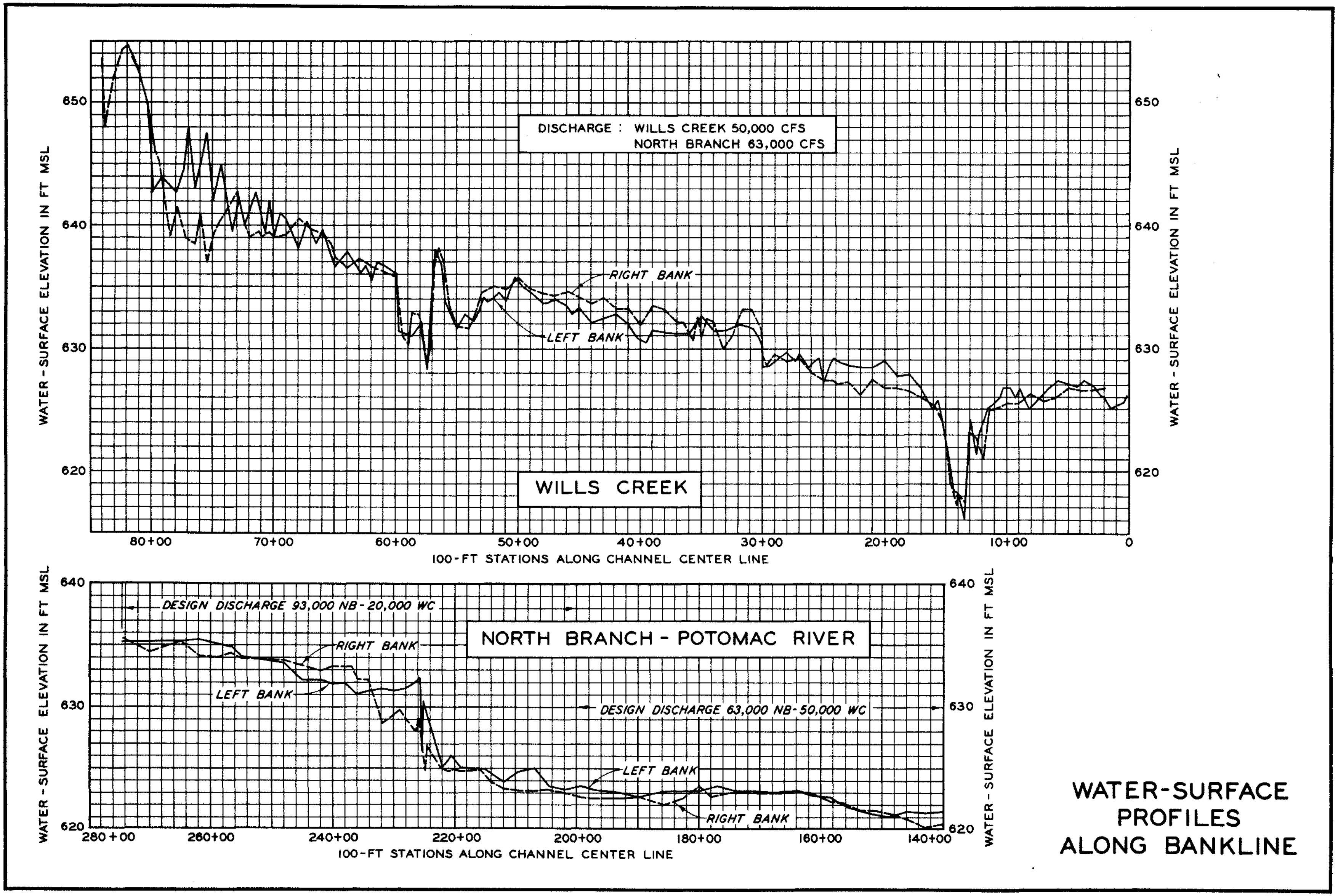

DISCHARGE : WILLS CREEK 50,000 CFS
NORTH BRANCH 63,000 CFS
RIGHT BANK
LEFT BANK
WILLS CREEK
WATER - SURFACE ELEVATION IN FT MSL
650
640
630
620
80+00
70+00
60+00
50+00
40+00
30+00
20+00
10+00
0
100-FT STATIONS ALONG CHANNEL CENTER LINE
DESIGN DISCHARGE 93,000 NB - 20,000 WC
NORTH BRANCH - POTOMAC RIVER
RIGHT BANK
LEFT BANK
DESIGN DISCHARGE 63,000 NB - 50,000 WC
LEFT BANK
RIGHT BANK
280+00
260+00
240+00
220+00
200+00
180+00
160+00
140+00
WATER-SURFACE
PROFILES
ALONG BANKLINE

PLATE 10